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WIND TUNNEL INVESTIGATION TO DETERMINE AERODYNAMIC CHARACTERISTICS OF A 0.03-SCALE MODEL OF THE TITAN III/MOL LAUNCH CONFIGURATION DURING THE ABORT SEQUENCE AT MACH NUMBERS FROM 0.60 TO 3.00

M. L. Homan and D. A. MacLanahan, Jr.

ARO, Inc.

August 1967

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per AF letter 25 Oct 72, William O Cole

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FOREWORD

The work reported herein was done at the request of the Space and Missiles Systems Organization (SAMSO), Air Force Systems Command (AFSC), for the Martin Company, under System Programs 632A and 623A.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from March 13 to April 24, 1967, under ARO Project No. PT0732, and the manuscript was submitted for publication on June 29, 1967.

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This technical report has been reviewed and is approved.

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ABSTRACT

A 0.03-scale model of the Titan III/Manned Orbiting Laboratory (MOL) launch vehicle was tested in Tunnels 16T and 16S of the Propulsion Wind Tunnel Facility at Mach numbers from 0.6 to 3.0 to obtain aerodynamic force and moment data on the airborne vehicle during the abort sequence. Test results show that there was a reduction in magnitude of the pitching-moment and normal-force coefficients at all angles of attack as jet pressure ratio (p_c/p_∞) was increased. Thrust termination (jet off to jet on) resulted in an increase in the magnitude of both the yawing-moment and side-force coefficients at all angles of attack.

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NOMENCLATURE

C_m	Pitching-moment coefficient, positive nose up, pitching moment/$q_\infty SD$
C_N	Normal-force coefficient, positive up, normal force/$q_\infty S$
C_n	Yawing-moment coefficient, positive nose right looking upstream, yawing moment/$q_\infty SD$
C_Y	Side-force coefficient, positive right looking upstream, side force/$q_\infty S$
D	Core diameter (reference diameter), 0.30 ft
F_N	Normal force, positive up, lb
F_y	Side force, positive right looking upstream, lb
M_m	Pitching moment, positive nose up, ft-lb
M_n	Yawing moment, positive nose right looking upstream, ft-lb
M_∞	Free-stream Mach number
p_c	Chamber pressure, psf
p_∞	Free-stream static pressure, psf

q_∞	Free-stream dynamic pressure, psf
S	Core cross-sectional area (reference area), 0.0707 ft^2
α	Model angle of attack, positive nose up, deg
β	Model angle of sideslip, positive nose left, looking upstream, deg

SECTION I
INTRODUCTION

The Titan III/MOL (Manned Orbiting Laboratory) launch system is a Titan 120-in.-diam core with two 120-in.-diam, seven-segment, strap-on, solid-propellant rocket motors (SRM's) and the MOL. The MOL is a 120-in.-diam cylinder with a Gemini B attached to the forward bulkhead. The flight crew occupies the Gemini B during launch.

During the time from liftoff, until the solid-propellant rocket motors burn out and are jettisoned, a malfunction could occur that would make it necessary to initiate an abort of the mission. An abort sequence is initiated by thrust termination - opening the exhaust ports in the nose of the solid-propellant rocket motors. The time available to the flight crew to escape from the vehicle is dependent upon the time required for the vehicle to reach an attitude which will ultimately result in a structural breakup.

A 0.03-scale model of the Titan III/MOL launch vehicle was tested in the Propulsion Wind Tunnel, Transonic (16T) and Propulsion Wind Tunnel, Supersonic (16S) of the Propulsion Wind Tunnel Facility (PWT) to obtain aerodynamic force and moment data on the vehicle during a simulated abort sequence. High pressure air was used to simulate the rocket exhaust from the thrust-termination ports which were located on the nose of the SRM's. No attempt was made to simulate the normal SRM rocket nozzle exhaust. Data were obtained at Mach numbers from 0.6 to 3.0 for model angles of attack and angles of sideslip from -35 to 35 deg.

This report is concerned only with the force phase of this test. The results from the pressure phase of the test are presented in Ref. 1.

SECTION II
APPARATUS

2.1 TEST FACILITIES

Tunnel 16T is a closed-circuit, continuous-flow wind tunnel that can be operated at Mach numbers from 0.55 to 1.60. The tunnel can be operated over a stagnation pressure range from approximately 160 to 4000 psfa and over a stagnation temperature range from 80 to 160°F. The tunnel specific humidity is controlled by removing the tunnel air and supplying conditioned makeup air from an atmospheric dryer. Perforated walls in the test section allow continuous operation through the Mach number range with a minimum of wall interference.

Tunnel 16S is a closed-circuit, continuous-flow wind tunnel that can be operated at Mach numbers from 1.65 to 3.20. The tunnel can be operated over a stagnation pressure range from 100 to approximately 1800 psfa. The test section stagnation temperature can be controlled through the range of 100 to 650°F. The tunnel specific humidity is controlled by removing tunnel air and supplying conditioned makeup air from an atmospheric dryer.

Details of the test sections showing model location and sting support arrangement are presented in Figs. 1a and b. A more extensive description of each tunnel and its operating characteristics is contained in Ref. 2.

2.2 MODEL GEOMETRY

The Titan III/MOL launch vehicle is a Titan III 120-in.-diam core with two 120-in.-diam, seven-segment, strap-on, solid-propellant rocket motors (SRM's) and the MOL. The MOL consists of a 120-in.-diam cylinder which is mounted aft of a Gemini B spacecraft. A sting-mounted 0.03-scale force model of the basic launch vehicle was tested in each tunnel. Major model details and dimensions are shown in Fig. 2. Typical model installations in the tunnels are shown in Figs. 3a and b.

2.2.1 Auxiliary Pitch Mechanism

To obtain the required angle of attack and angle of sideslip range for these tests, the test article was supported in the wind tunnel by means of a remotely operated, cantilevered sting attached to the basic sting support system of the tunnel. This auxiliary pitch mechanism can be operated from -11 to 30 deg in one plane only. In order to obtain angles of sideslip or combinations of angle of attack and angle of sideslip, the model, forward of this mechanism, must be rolled manually. For these tests the model could be rolled forward of the mechanism in 45-deg increments from 0 to 360 deg.

2.2.2 Thrust Termination Simulation System

High pressure air was used to simulate the solid-propellant rocket exhausts that would be exhausting through the thrust termination ports on the nose of the SRM's during the abort sequence. Each SRM contains an internal tank which provides a stilling chamber for the air supplied to the thrust termination ports. The air is supplied through the aft end of each SRM from a high pressure supply located outside the tunnel shell. The internal tanks were supported by the sting and in the model by a four-component balance free to move in the axial direction. Internal details of the model and the thrust termination port are shown in Figs. 4 and 5, respectively.

2.3 INSTRUMENTATION

An internally mounted, six-component, strain-gage balance was used to measure model forces and moments. An additional, internally mounted, four-component, strain-gage balance, free to move in the axial direction, was used to measure the forces and moments transmitted to the model by the thrust termination supply tanks. The chamber pressure of the thrust-termination simulation system was measured by two model-mounted transducers.

Outputs from the balance and pressure transducers were digitized and code punched on paper tape for on-line data reduction. The balance outputs were also continuously recorded on a direct-writing oscillograph for monitoring model dynamics.

SECTION III
TEST DESCRIPTION

3.1 PROCEDURE

For a given model roll angle forward of the auxiliary pitch mechanism, angles of attack (α) and angles of sideslip (β) over the range available were obtained by remotely pitching and rolling the main support mechanism, and remotely pitching the auxiliary pitch mechanism.

Data were obtained while holding Mach number and thrust-termination chamber pressure ratio (p_c/p_∞) constant and varying α and β. During the majority of testing, p_c/p_∞ was held at a nominal value for each test Mach number. This nominal value corresponds to the p_c/p_∞ ratio required to simulate the solid-propellant rocket exhaust at that Mach number. At all test Mach numbers, data were obtained with no thrust-termination simulation (jet off) and, for certain test Mach numbers, jet pressure ratio was varied above and below the nominal value. The nominal chamber pressure ratios during these tests are shown in Fig. 6. The model was tested at Mach numbers from 0.6 to 1.4 in Tunnel 16T and from 1.8 to 3.0 in Tunnel 16S.

3.2 DATA REDUCTION

The normal- and side-force, and pitching- and yawing-moment data obtained were corrected for the normal force, side force, pitching moment and yawing moment that the thrust-termination supply tanks imposed on the

model. As a result of friction, axial force from the supply tanks was transmitted to the main balance and prevented acquisition of accurate axial-force data. The force and moments were corrected for weight tares and were reduced to coefficient form in the body axis system. Pitching and yawing moments were referred to a common model station 19.556 in. aft of the nose. All force and moment coefficients were based on core diameter and cross-sectional area.

3.3 PRECISION OF MEASUREMENTS

An estimate of the accuracy of measurements in 16T and 16S is presented in the following table. The maximum variation in centerline Mach number in 16T is ±0.005 at $M_\infty = 0.6$ and ±0.016 at $M_\infty = 1.5$. The maximum variation in centerline Mach number in 16S is ±0.02, and the off-centerline Mach number agrees with centerline Mach number within ±0.01. The uncertainties in force and moment coefficients include the errors associated with balance zero shifts and calibration curve fits.

M_∞	$\pm\alpha$, deg	$\pm\beta$, deg	$\pm q_\infty$, psf	$\pm C_m$	$\pm C_N$	$\pm C_n$	$\pm C_Y$
0.8	0.2	0.2	6.0	1.683	0.311	1.398	0.257
1.2	0.2	0.2	6.0	1.257	0.233	1.480	0.276
2.2	0.2	0.2	4.0	1.988	0.369	1.573	0.293
3.0	0.2	0.2	4.0	3.227	0.601	2.694	0.503

SECTION IV
RESULTS AND DISCUSSION

The purpose of this phase of the tests was to obtain aerodynamic characteristics of a 0.03-scale model of the Titan III/MOL launch vehicle during a simulated abort sequence at Mach numbers from 0.6 to 3.0. The results of the investigation of the Titan III/MOL launch vehicle during a simulated abort sequence are presented in two general categories: (1) effect of the jet pressure ratio (p_c/p_∞) of the thrust-termination simulator on model aerodynamic characteristics and (2) effect of model attitude, at nominal trajectory flight conditions, on model aerodynamic characteristics.

4.1 EFFECTS OF JET PRESSURE RATIO

The effects of jet pressure ratio on pitching-moment and normal-force coefficients throughout the angle-of-attack range are presented in Figs. 7 and 8, respectively, for the various test Mach numbers. There was a reduction in magnitude of the pitching-moment and normal-force coefficients at all angles of attack as jet pressure ratio increased. This was more pronounced at the higher Mach numbers where the magnitude of the jet pressure ratio was larger.

Yawing-moment and side-force coefficients, as a function of angle of sideslip for zero angle of attack, are shown in Figs. 9 and 10 for various jet pressure ratios. Execution of the abort (thrust-termination) firing sequence, i.e., jets-off to jets-on, resulted in large increases in the magnitude of the yawing-moment and side-force coefficients. These effects were more pronounced at subsonic and low supersonic Mach numbers.

The static longitudinal and directional stability characteristics of the Titan III/MOL model are presented in Figs. 11 and 12. Data are presented for no thrust-termination simulation (jets-off, $p_c/p_\infty = 1.0$) and thrust-termination simulation (jets-on). Thrust-termination simulation at all Mach numbers resulted in a rearward shift in the center of pressure in both the pitch and yaw planes. In general, this center-of-pressure shift decreased as Mach number increased.

4.2 EFFECT OF MODEL ATTITUDE

The results presented in this section pertain to thrust-termination simulation (jets-on) at the nominal trajectory jet pressure ratios.

The effects of angle of sideslip on the pitching-moment coefficient for various Mach numbers throughout the angle-of-attack range are presented in Fig. 13. At constant angle of attack, increasing the magnitude of sideslip angle increased the magnitude of the pitching-moment coefficient. This effect was pronounced throughout the range of the data.

Normal-force coefficient is shown as a function of angle of attack with angle of sideslip as a parameter in Fig. 14. Significant changes in the slope of C_N versus α curves occurred for angles of sideslip greater than ±10 deg, and this effect was more pronounced at subsonic and low supersonic Mach numbers.

Yawing-moment coefficient is shown as a function of angle of sideslip for various angles of attack in Fig. 15. At Mach number 0.8, large

decreases in yawing-moment magnitude occurred at the higher angles of attack. At supersonic Mach numbers this trend was reversed and was more pronounced for intermediate values of α at high positive β. The effect of angle of attack on side-force coefficient throughout the angle-of-sideslip range is presented in Fig. 16. Significant changes in side-force coefficient at all angles of sideslip occurred only in the initial ±10-deg change of angle of attack.

SECTION V
CONCLUDING REMARKS

Aerodynamic force and moment data were obtained for a Titan III/MOL during a simulated abort sequence at Mach numbers from 0.6 to 3.0. The results of the investigation are summarized below.

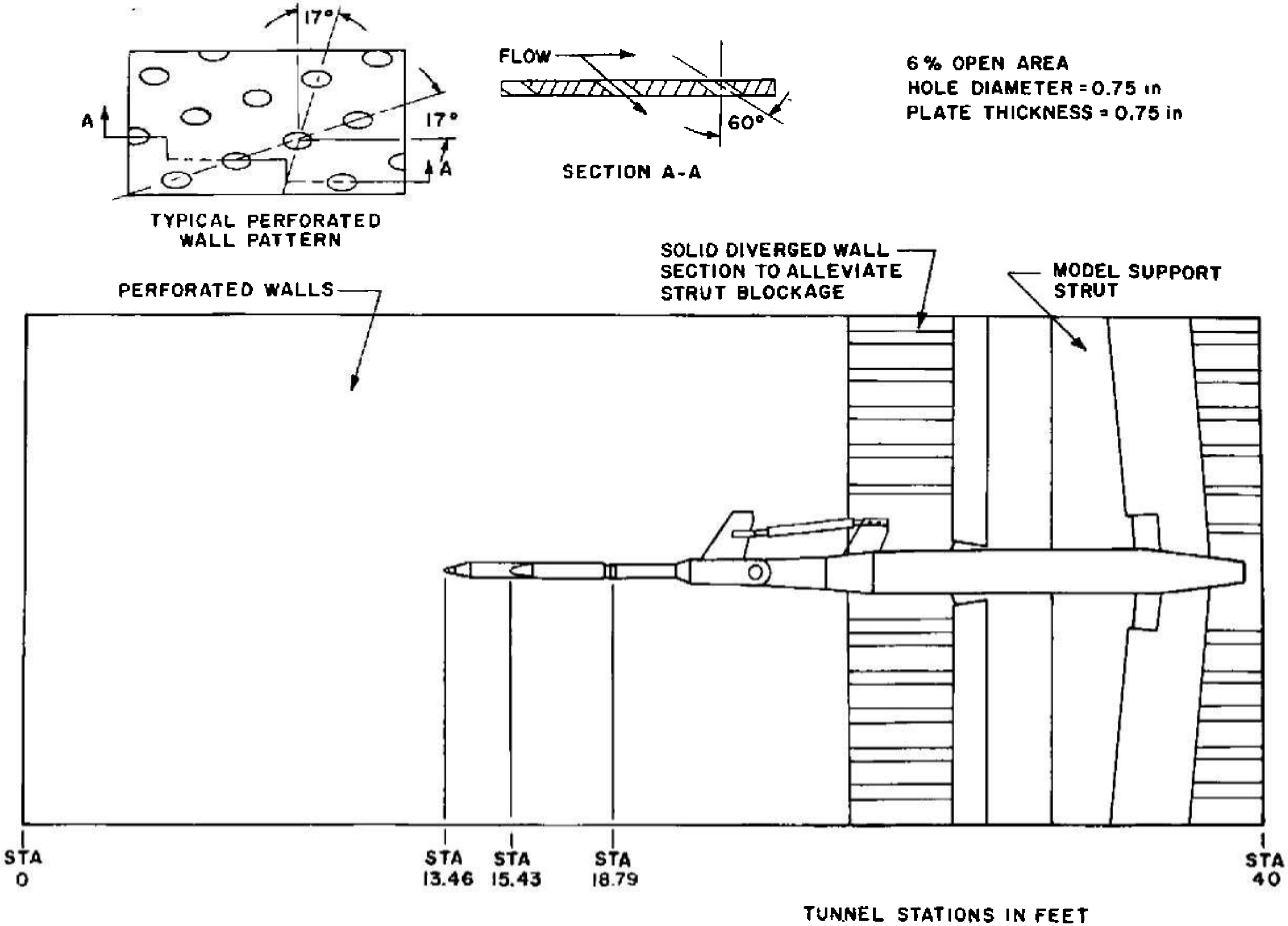
1. There was a reduction in magnitude of the pitching-moment and normal-force coefficients at all angles of attack as jet pressure ratio (p_c/p_∞) was increased.
2. Thrust termination (jets-off to jets-on) resulted in an increase in the magnitude of both the yawing-moment and side-force coefficient at all angles of sideslip. These effects were more pronounced at subsonic and low supersonic Mach numbers.
3. Thrust-termination simulation at all Mach numbers resulted in a rearward shift of the center of pressure in both the pitch and yaw planes.
4. The magnitude of the pitching-moment coefficient increased with magnitude of sideslip angle for constant angles of attack.
5. Significant changes in the slope of C_N versus α curves occurred for angles of sideslip greater than ±10 deg, and this effect was more pronounced at subsonic and low supersonic Mach numbers.
6. Significant changes in side-force coefficient at all angles of sideslip occurred only in the initial ±10-deg change of angle of attack at all test Mach numbers.

REFERENCES

1. MacLanahan, D. A. and Homan, M. L. "Wind Tunnel Investigation to Determine Pressure Distribution Characteristics of a 0.03-Scale Model of the Titan III/MOL Launch Configuration during the Abort Sequence at Mach Numbers from 0.60 to 3.00." AEDC-TR-67-141, July 1967.

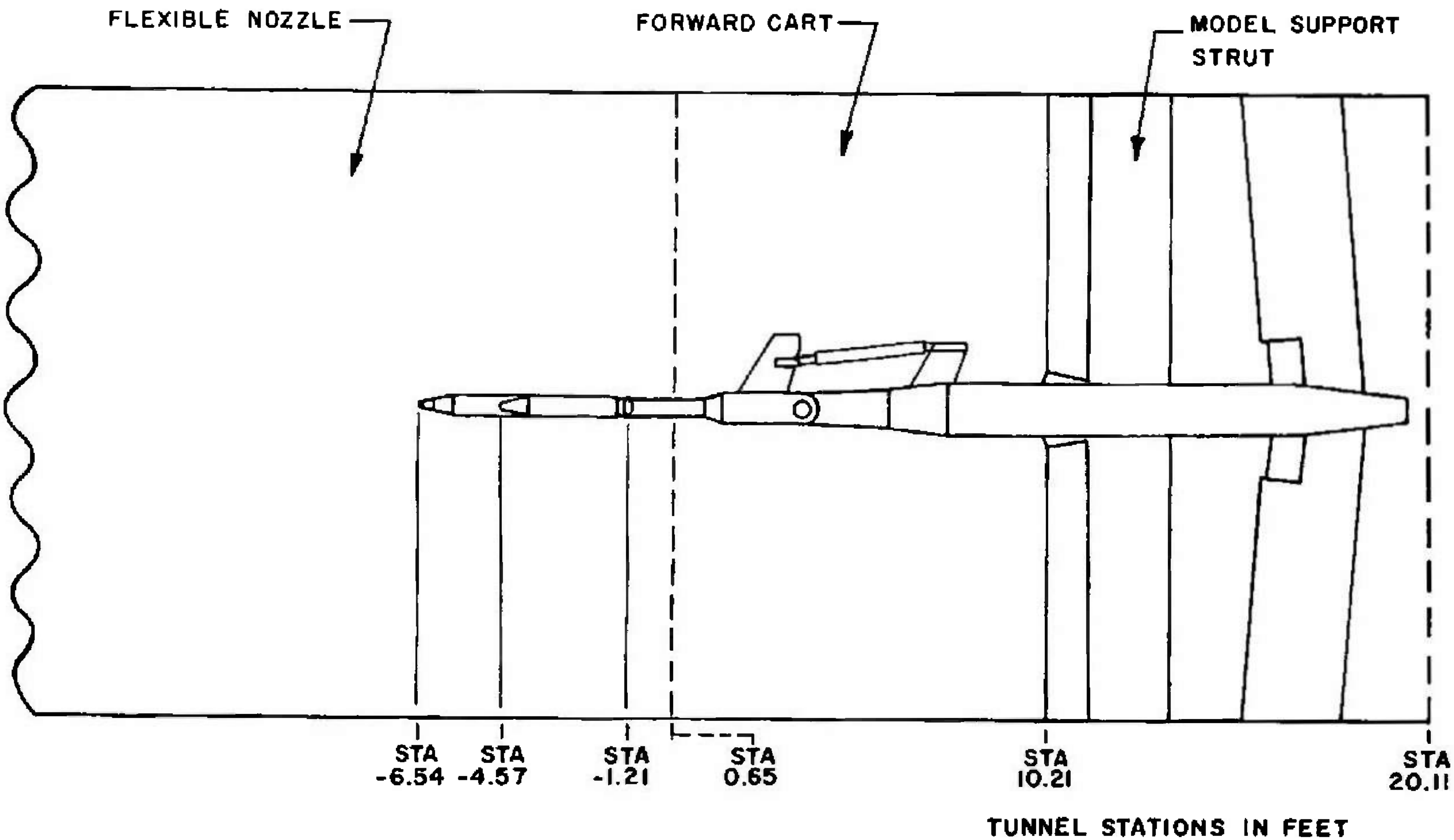
2. <u>Test Facilities Handbook</u> (6th Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, November 1966.

APPENDIX
ILLUSTRATIONS



a. 16T

Fig. 1 Location of Model in Test Section



b. 16S

Fig. 1 Concluded

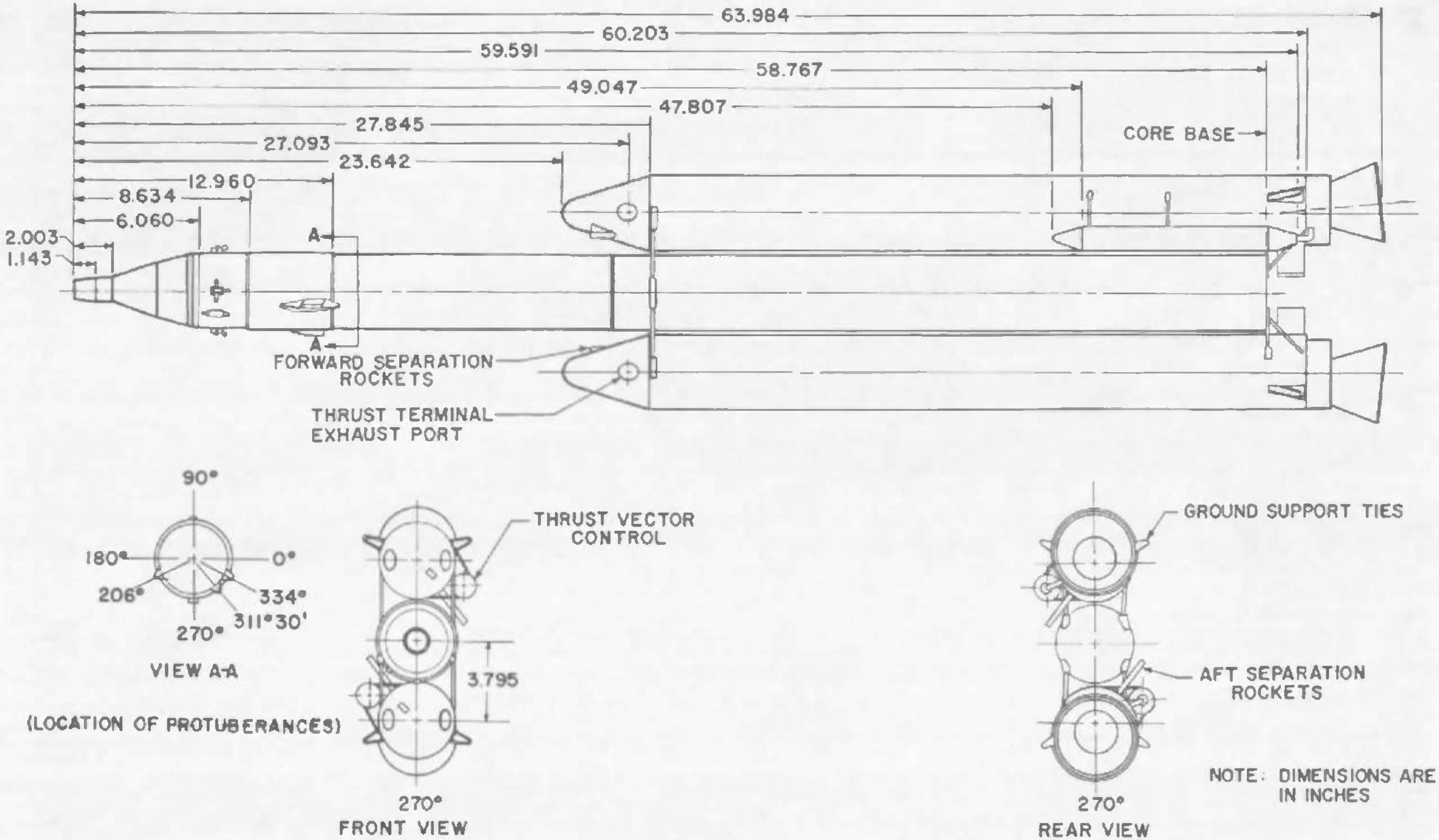
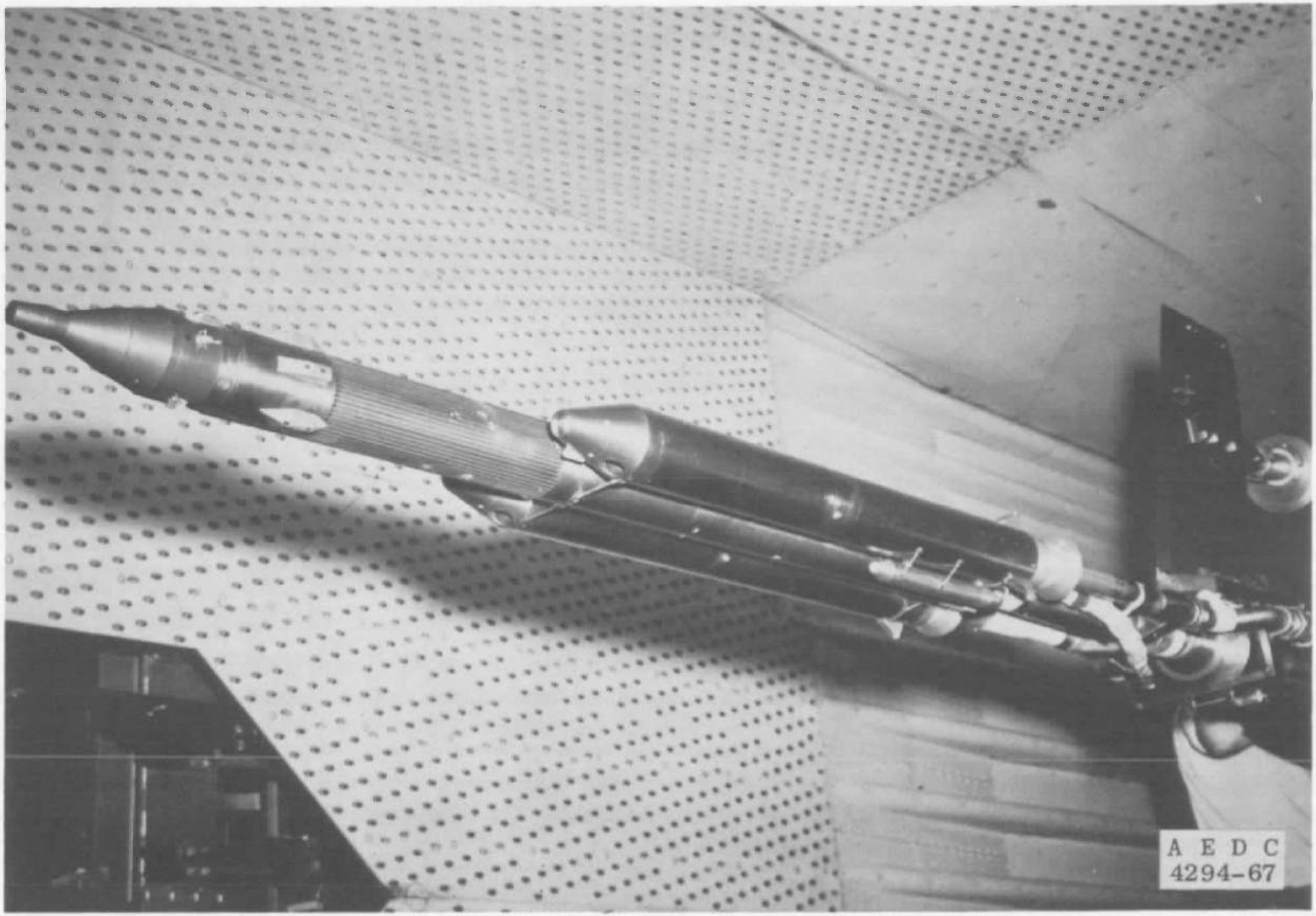
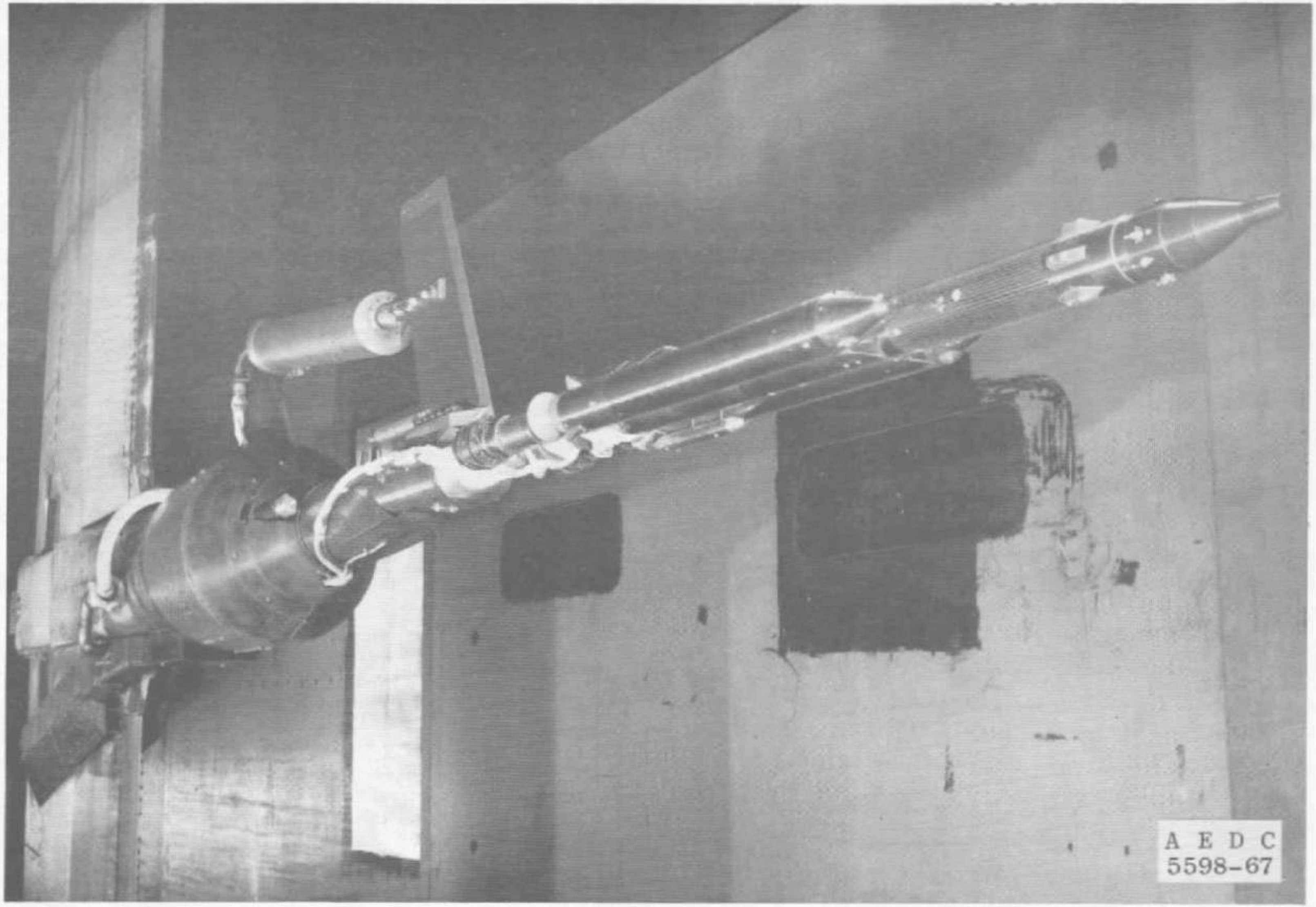


Fig. 2 Model Details



a. 16T

Fig. 3 Photograph of Model Installed in Test Section



b. 16S

Fig. 3 Concluded

1. THRUST-TERMINATION AIR SUPPLY TANKS
2. MAIN BALANCE
3. HIGH PRESSURE AIR SUPPLY LINE
4. STING
5. THRUST-TERMINATION EXHAUST PORT
6. THRUST-TERMINATION SUPPLY TANK BALANCE (FREE TO MOVE IN THE AXIAL DIRECTION)
7. SRM
8. TVC

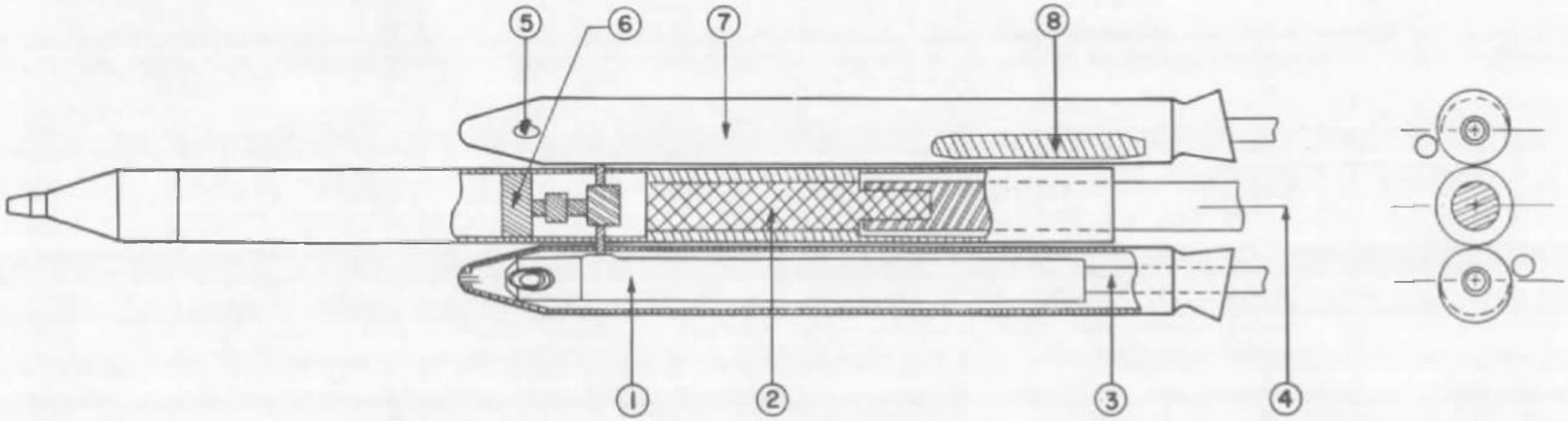
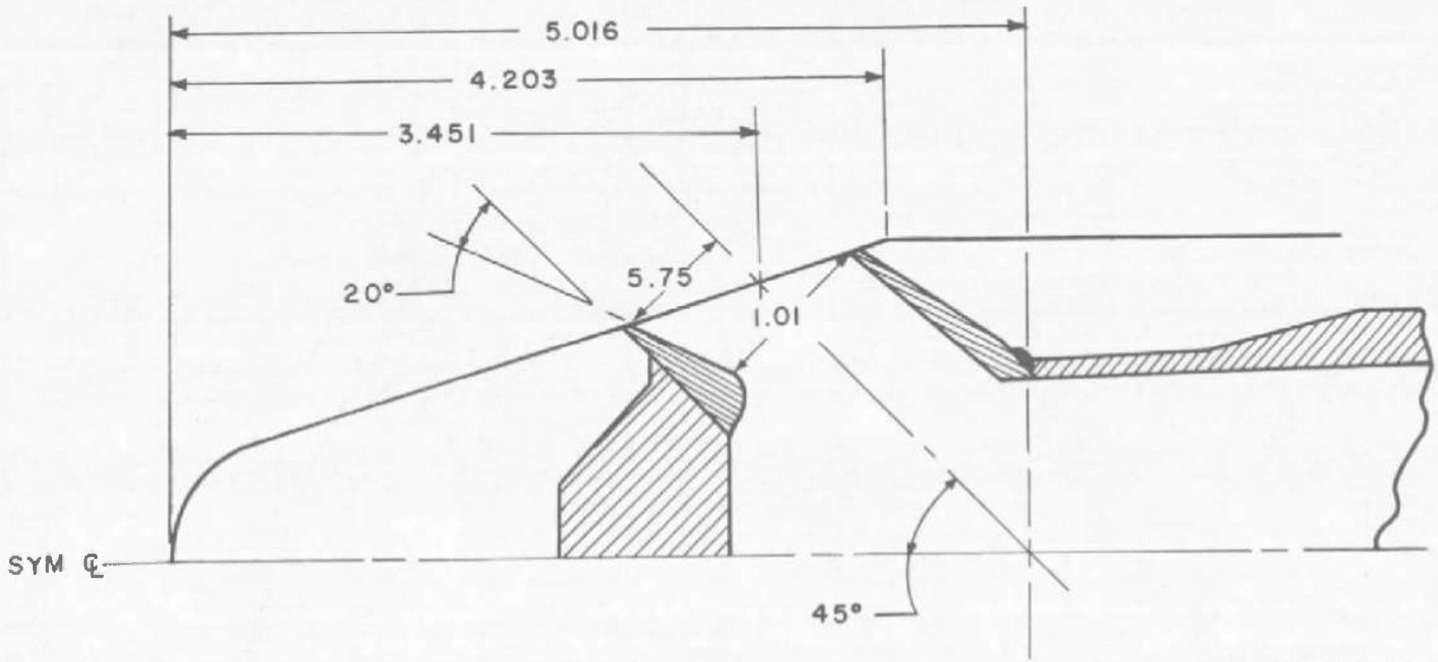


Fig. 4 Model Internal Details



NOTE: DIMENSIONS IN INCHES

Fig. 5 Thrust-Termination Port Details

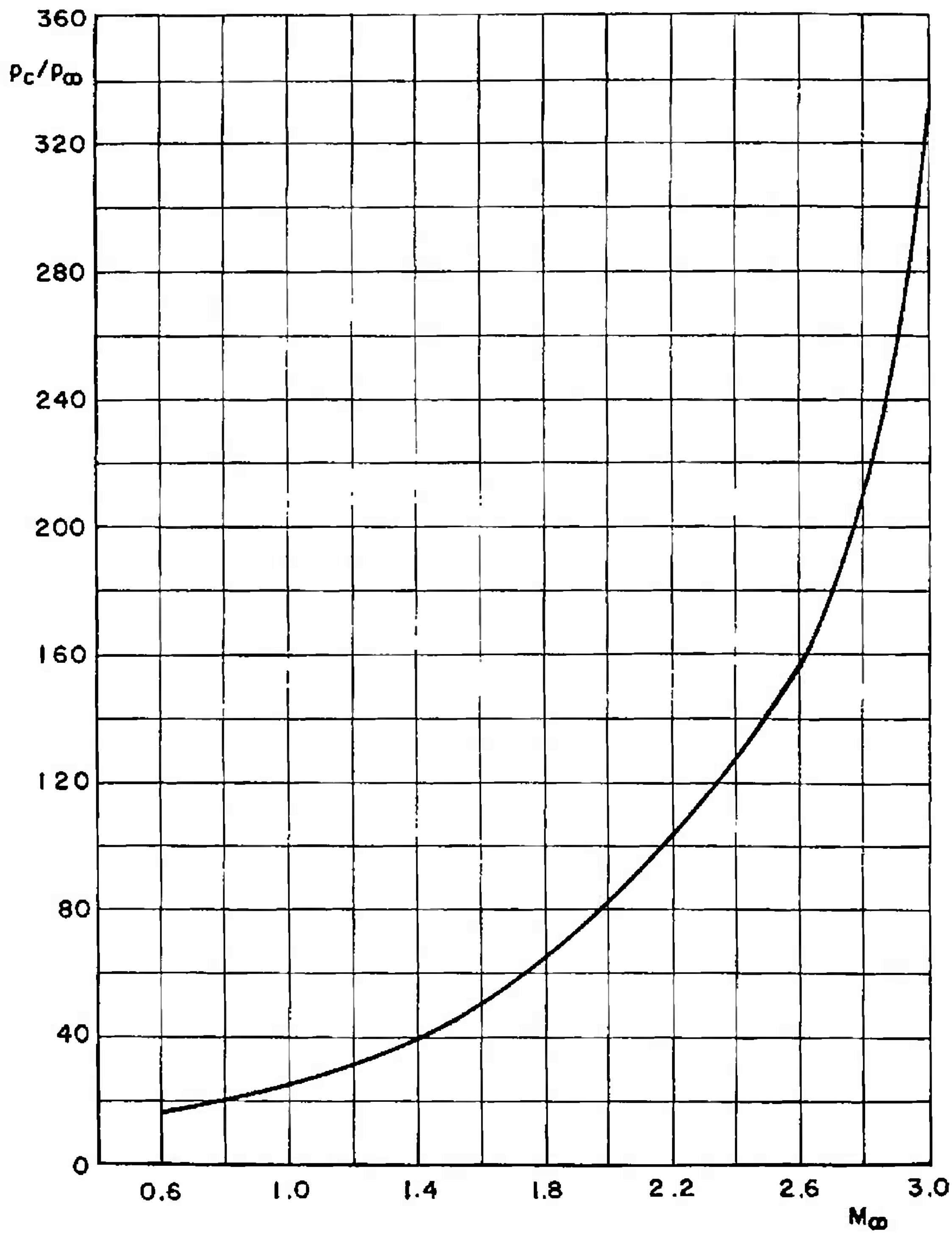
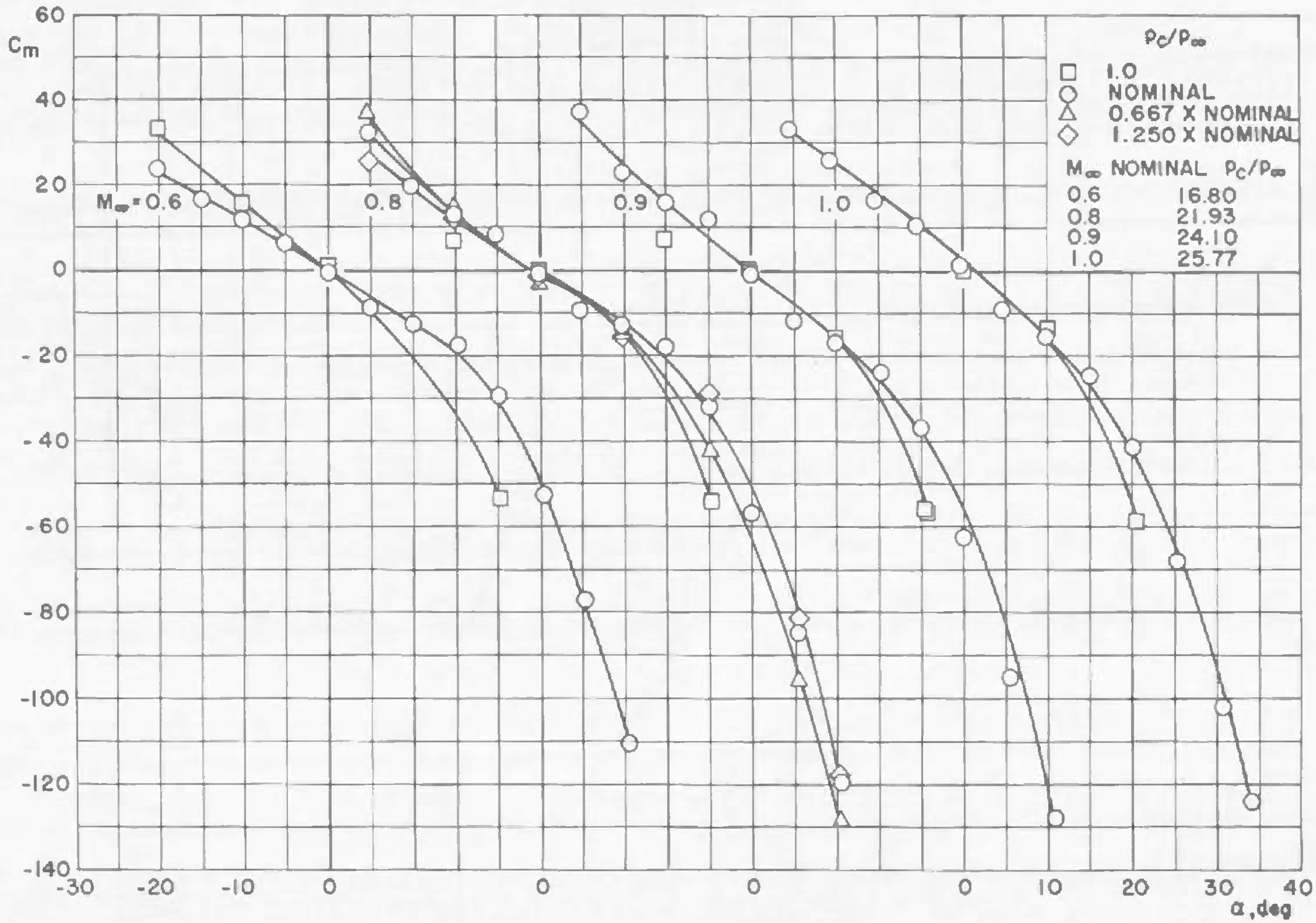
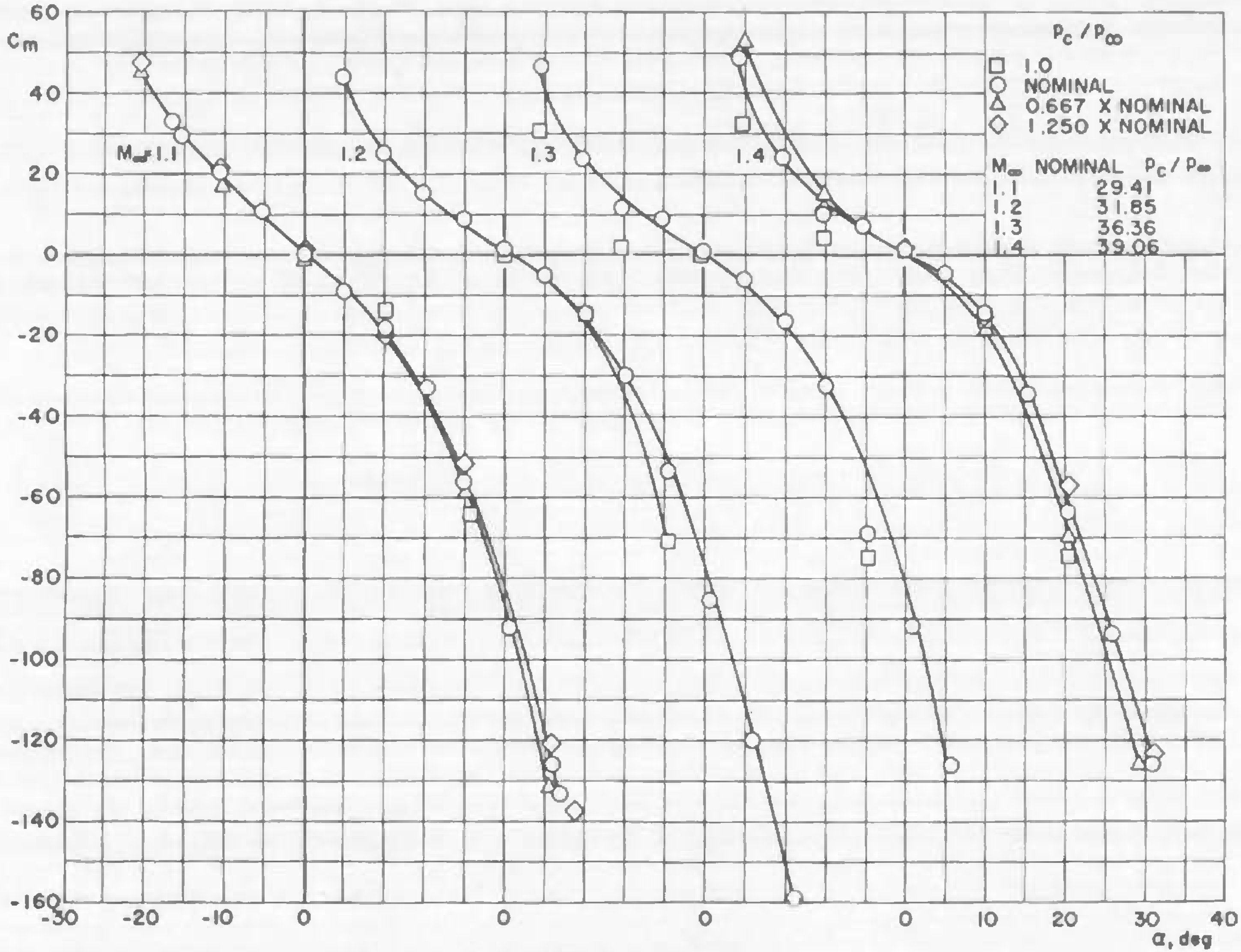


Fig. 6 Pressure Ratio Required for Nominal Trajectory



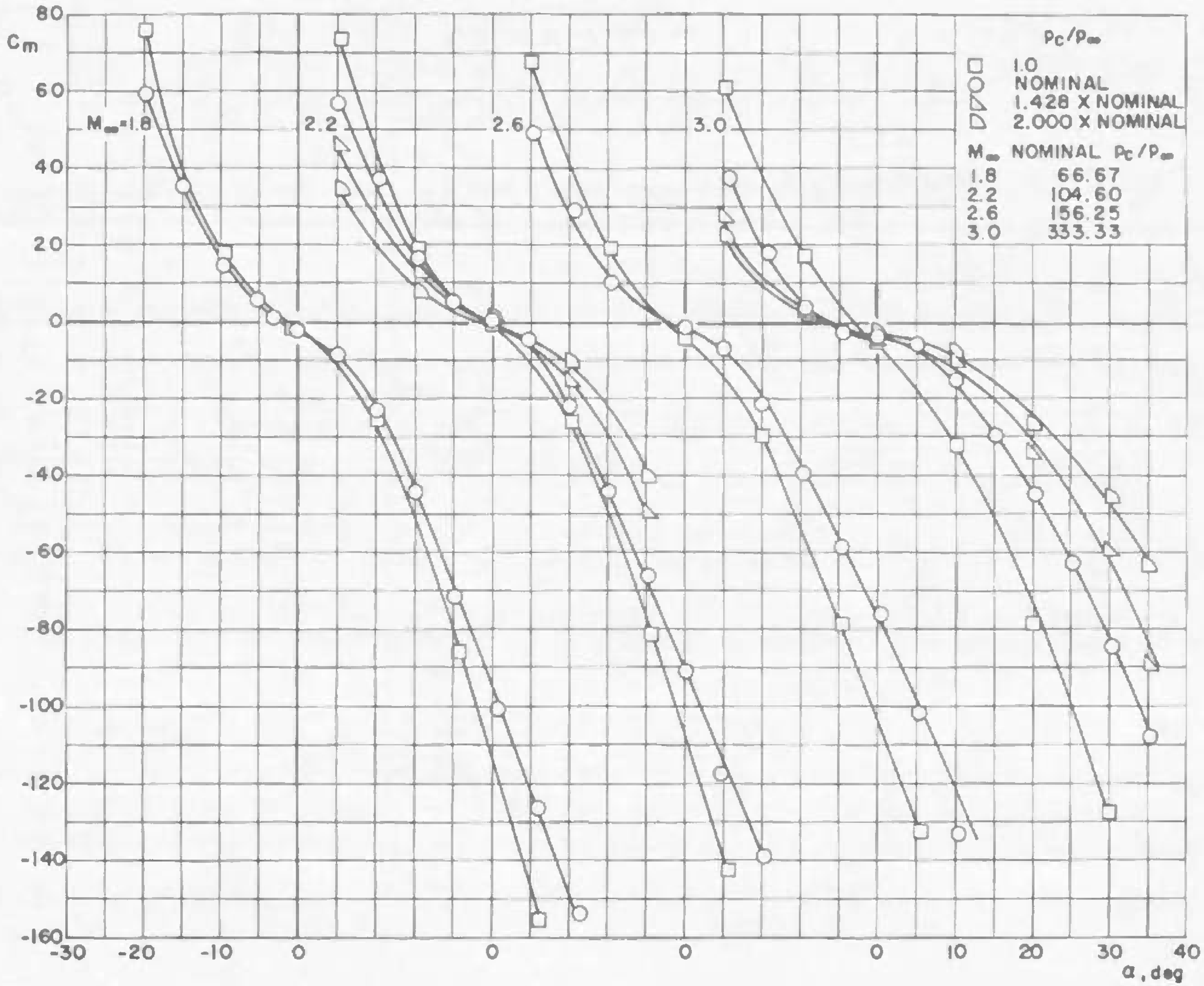
a. Mach Numbers 0.6 to 1.0

Fig. 7 Effect of Jet Pressure Ratio on Pitching-Moment Coefficient for Various Mach Numbers throughout the Angle-of-Attack Range, β = 0 deg



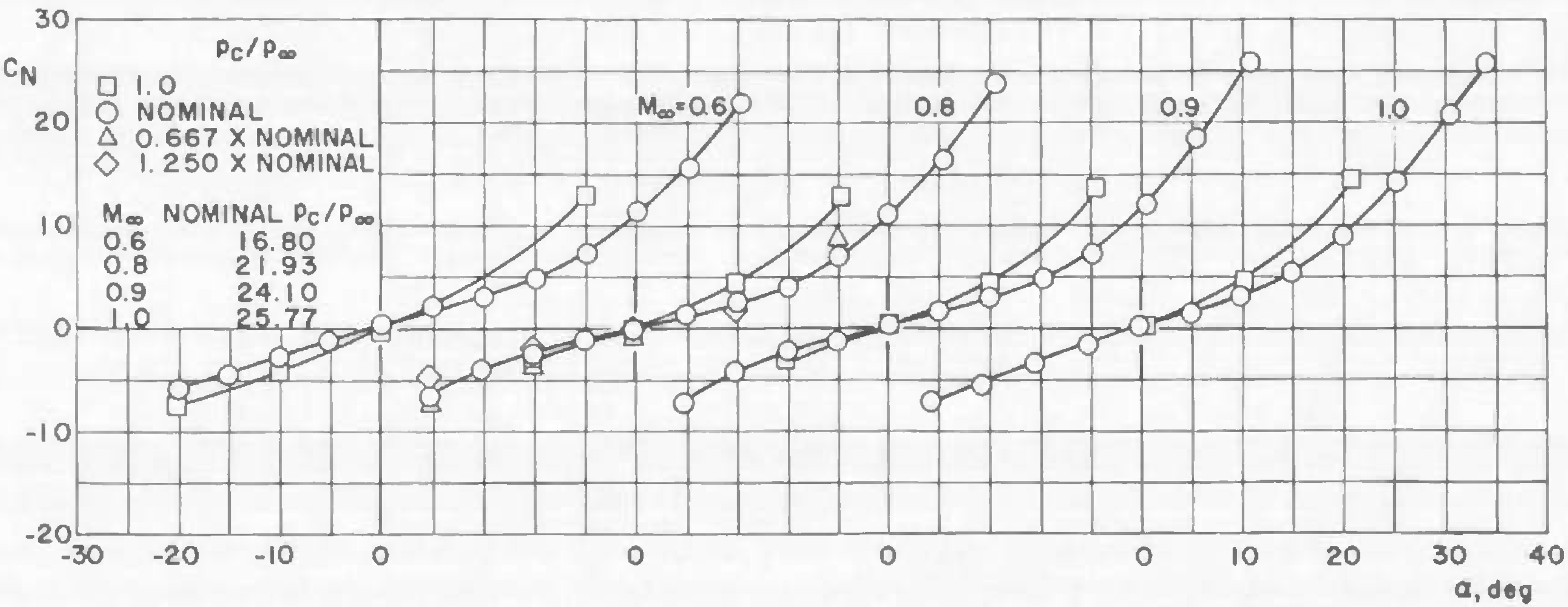
b. Mach Numbers 1.1 to 1.4

Fig. 7 Continued



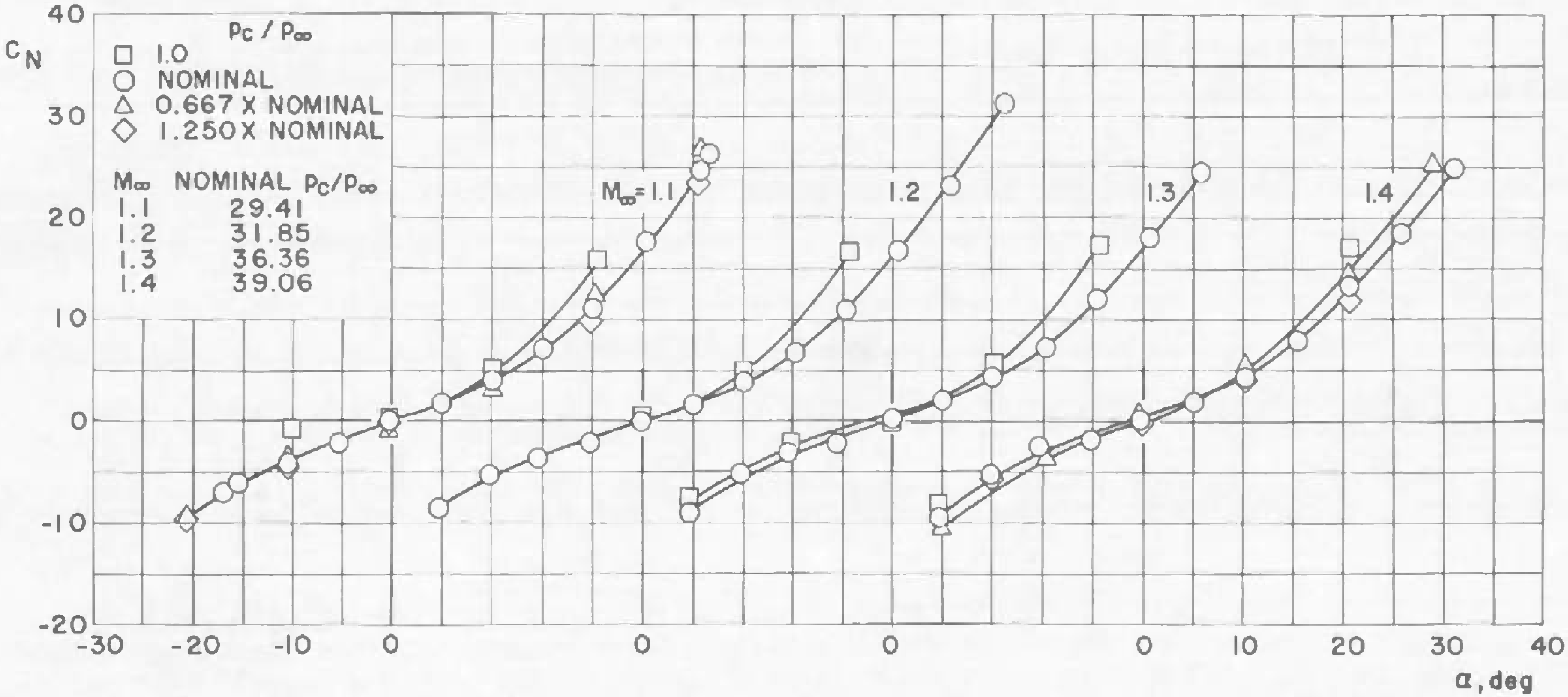
c. Mach Numbers 1.8 to 3.0

Fig. 7 Concluded



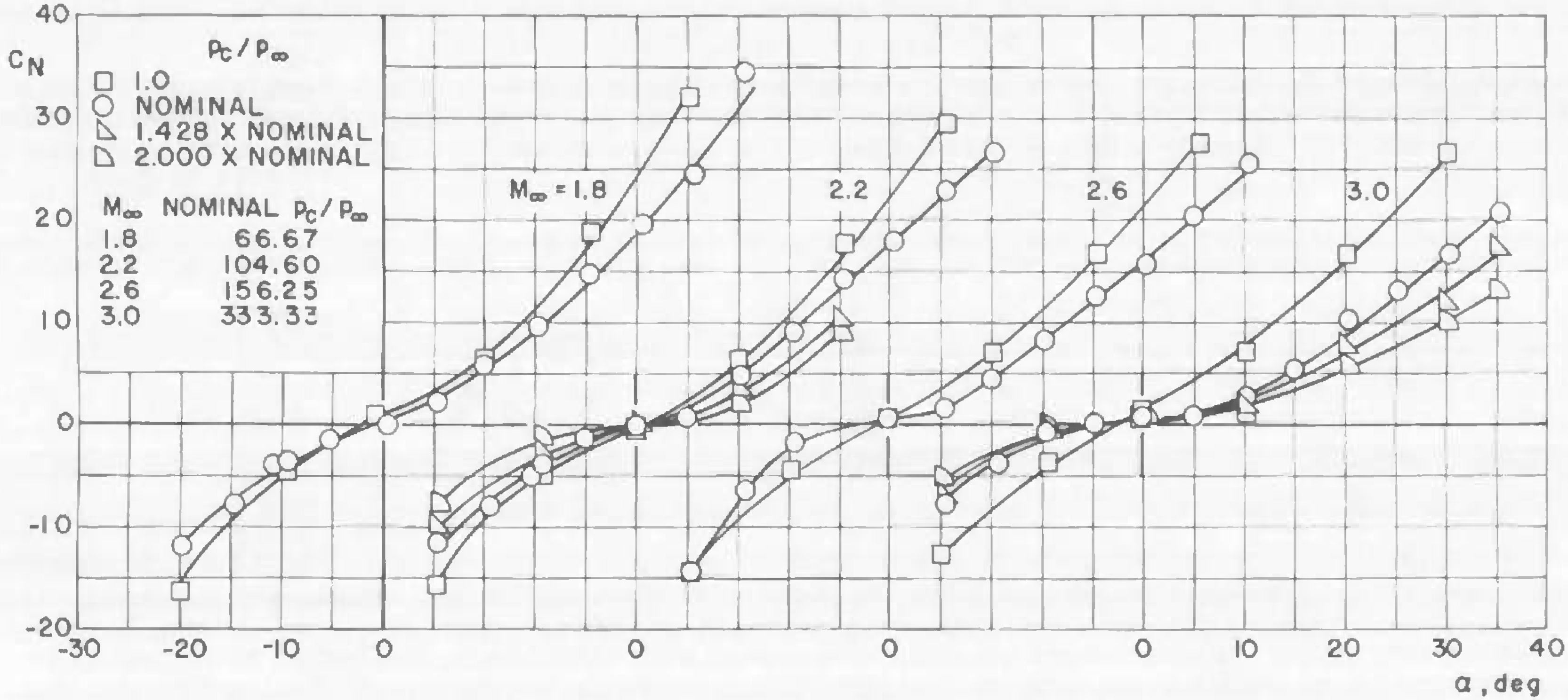
a. Mach Numbers 0.6 to 1.0

Fig. 8 Effect of Jet Pressure Ratio on Normal-Force Coefficient for Various Mach Numbers throughout the Angle-of-Attack Range, $\beta = 0$ deg



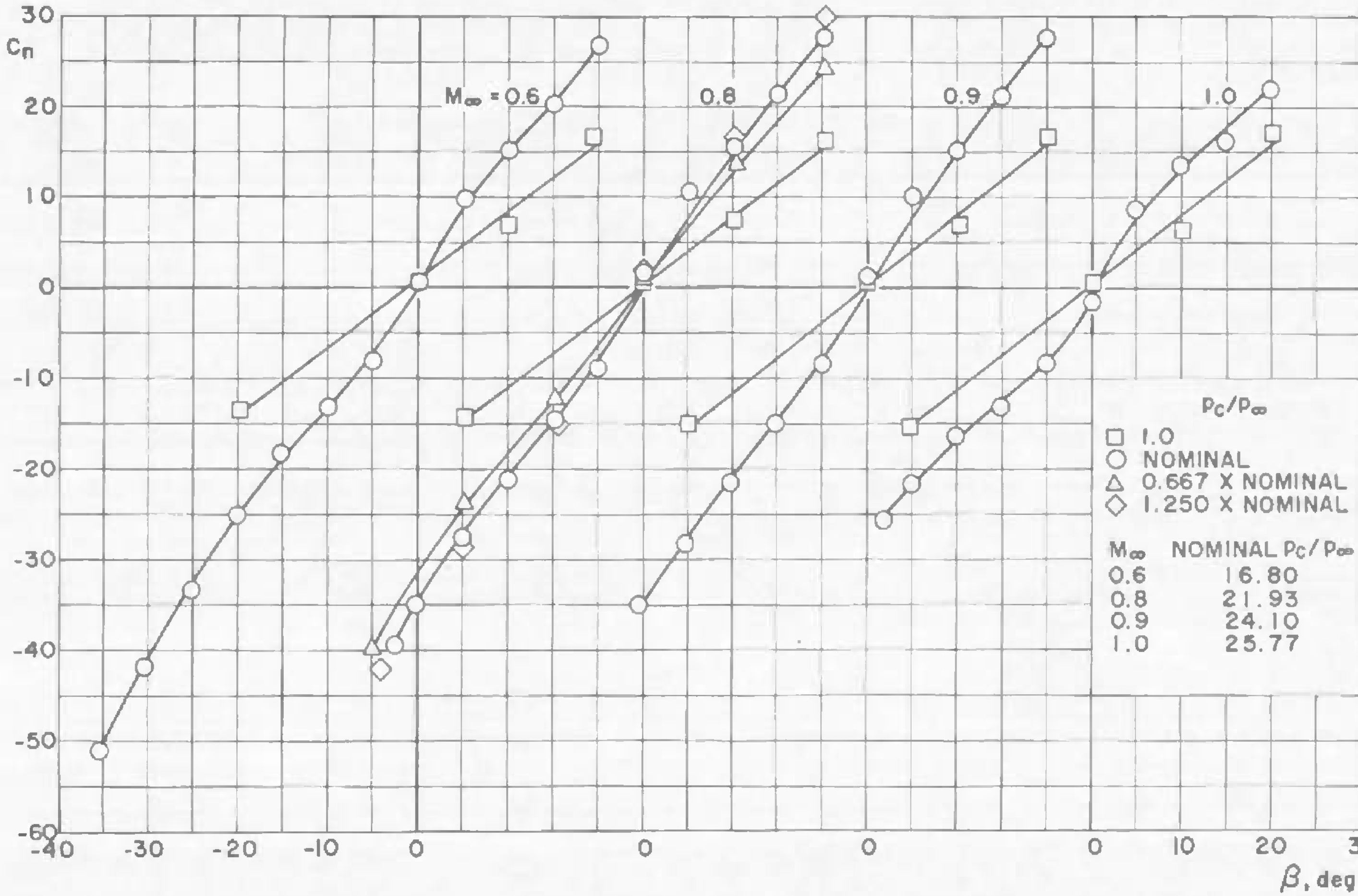
b. Mach Numbers 1.1 to 1.4

Fig. 8 Continued



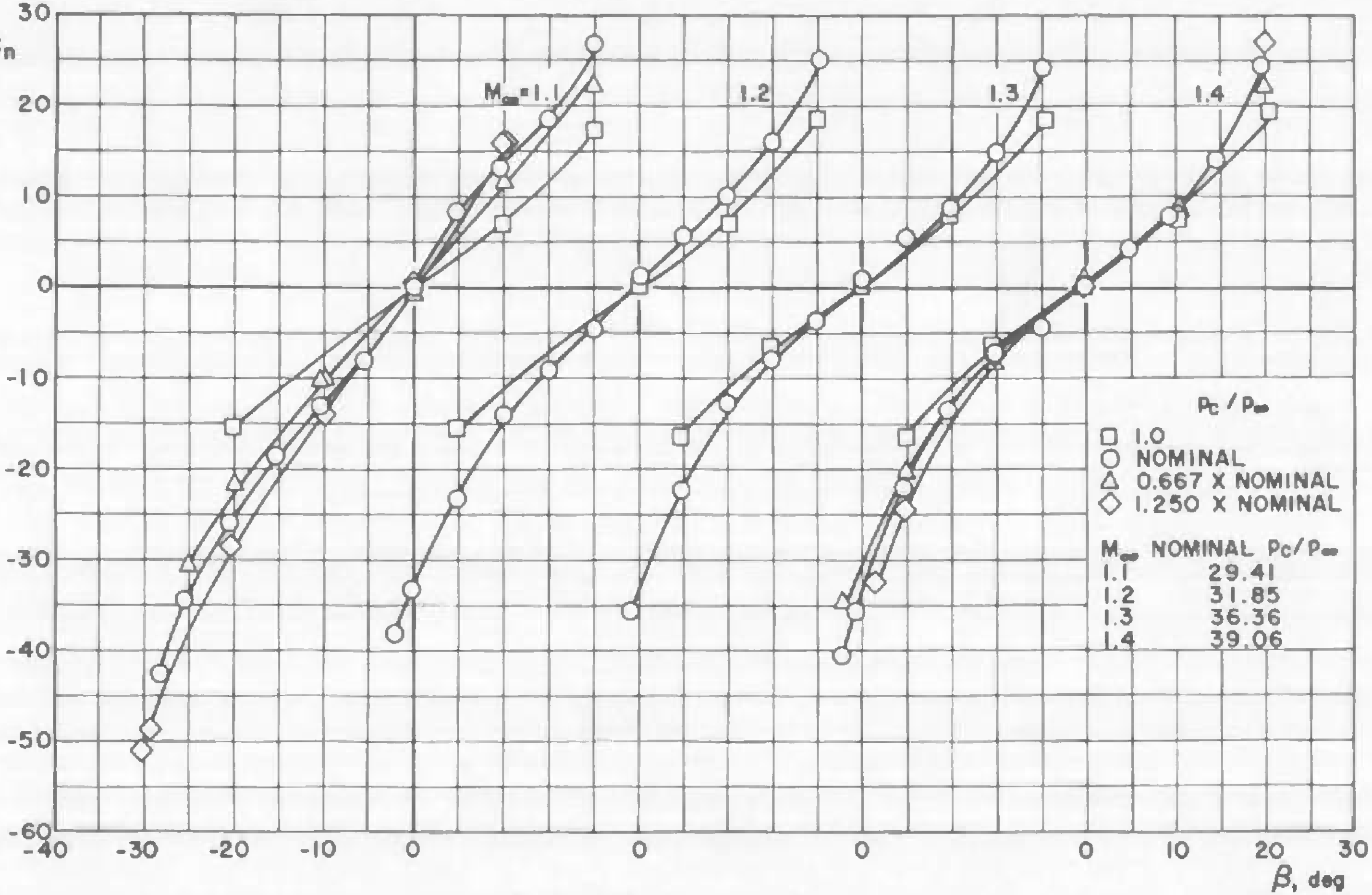
c. Moch Numbers 1.8 to 3.0

Fig. 8 Concluded



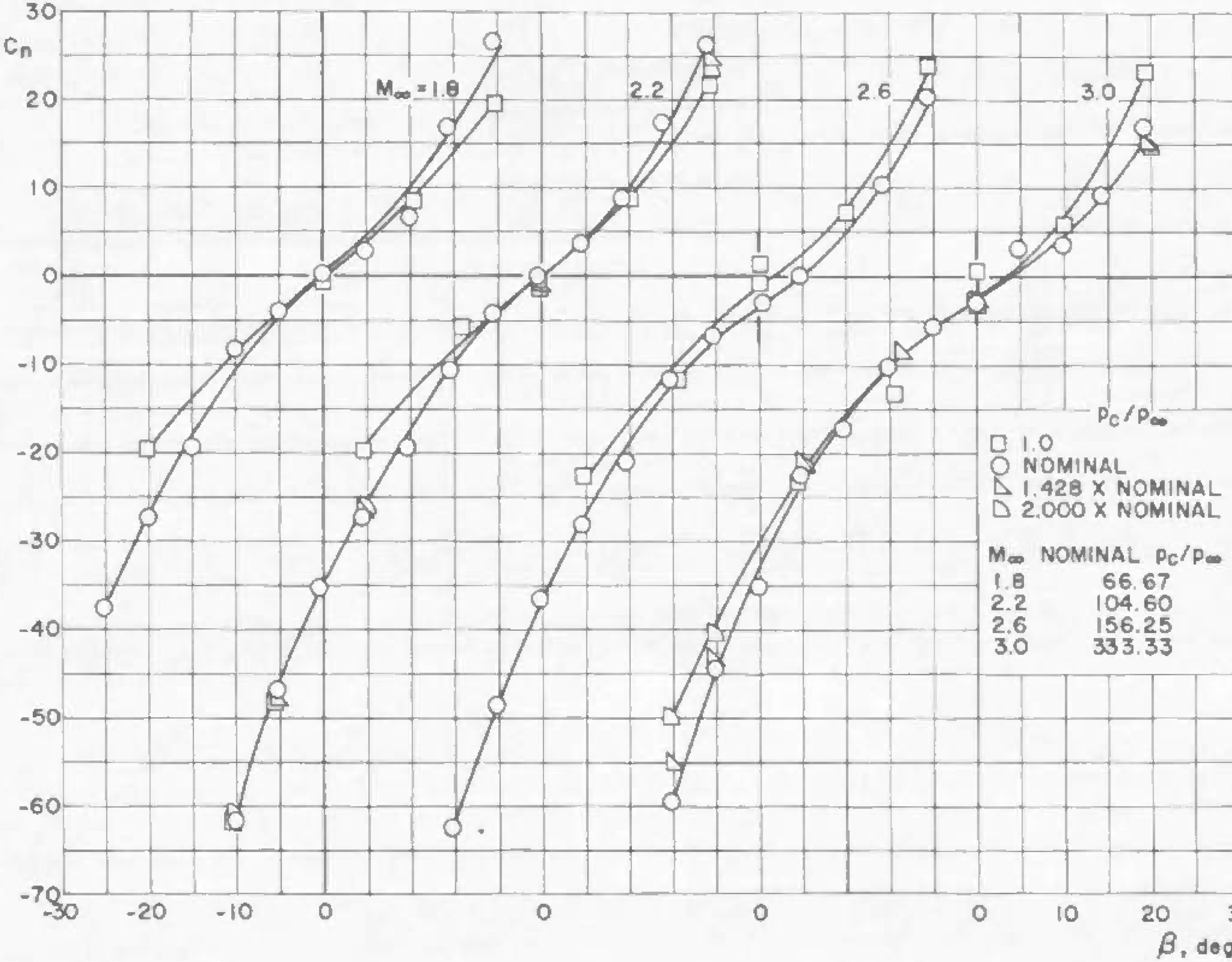
a. Mach Numbers 0.6 to 1.0

Fig. 9 Effect of Jet Pressure Ratio on Yawing-Moment Coefficient for Various Mach Numbers throughout the Angle-of-Sideslip Range, $\alpha = 0$ deg



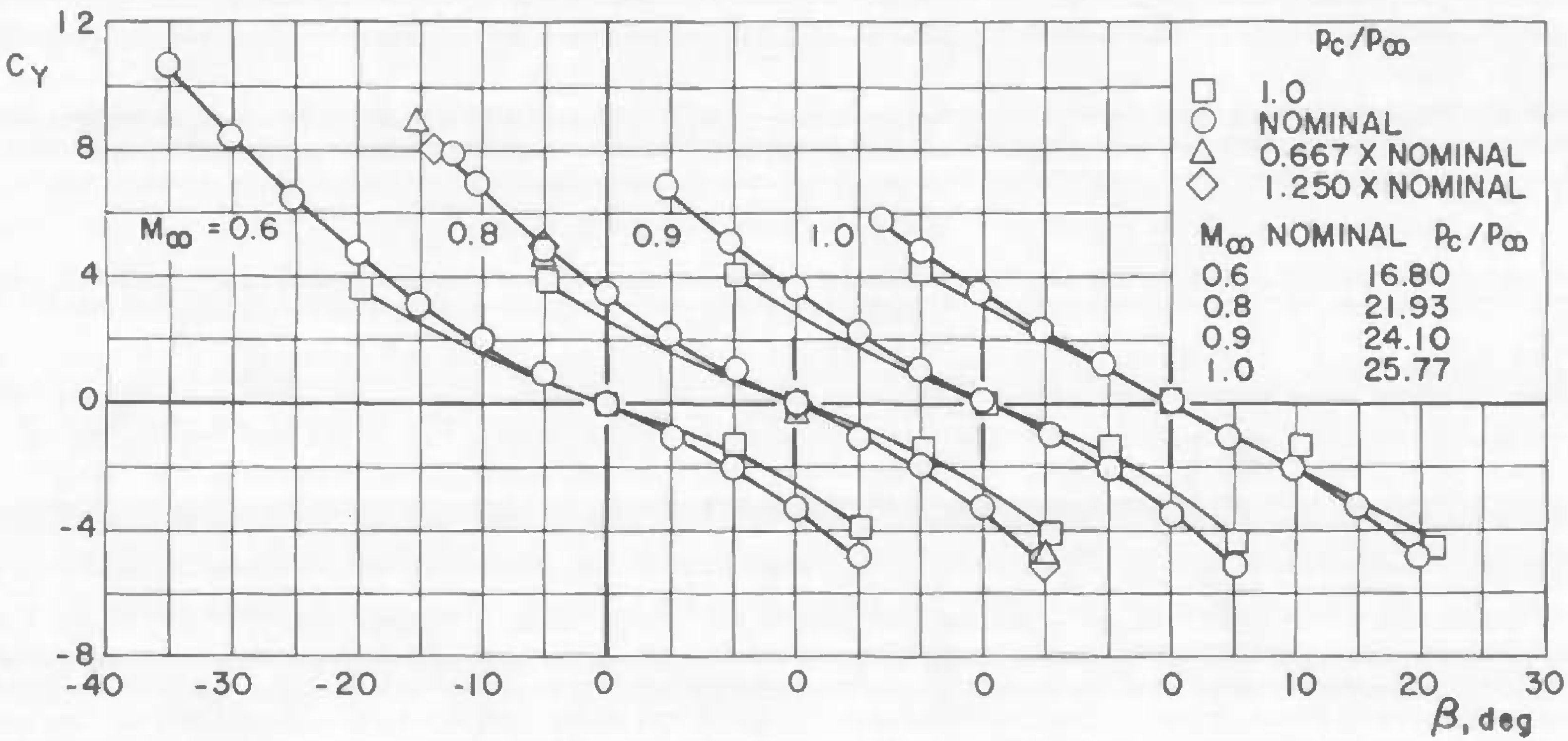
b. Mach Numbers 1.1 to 1.4

Fig. 9 Continued



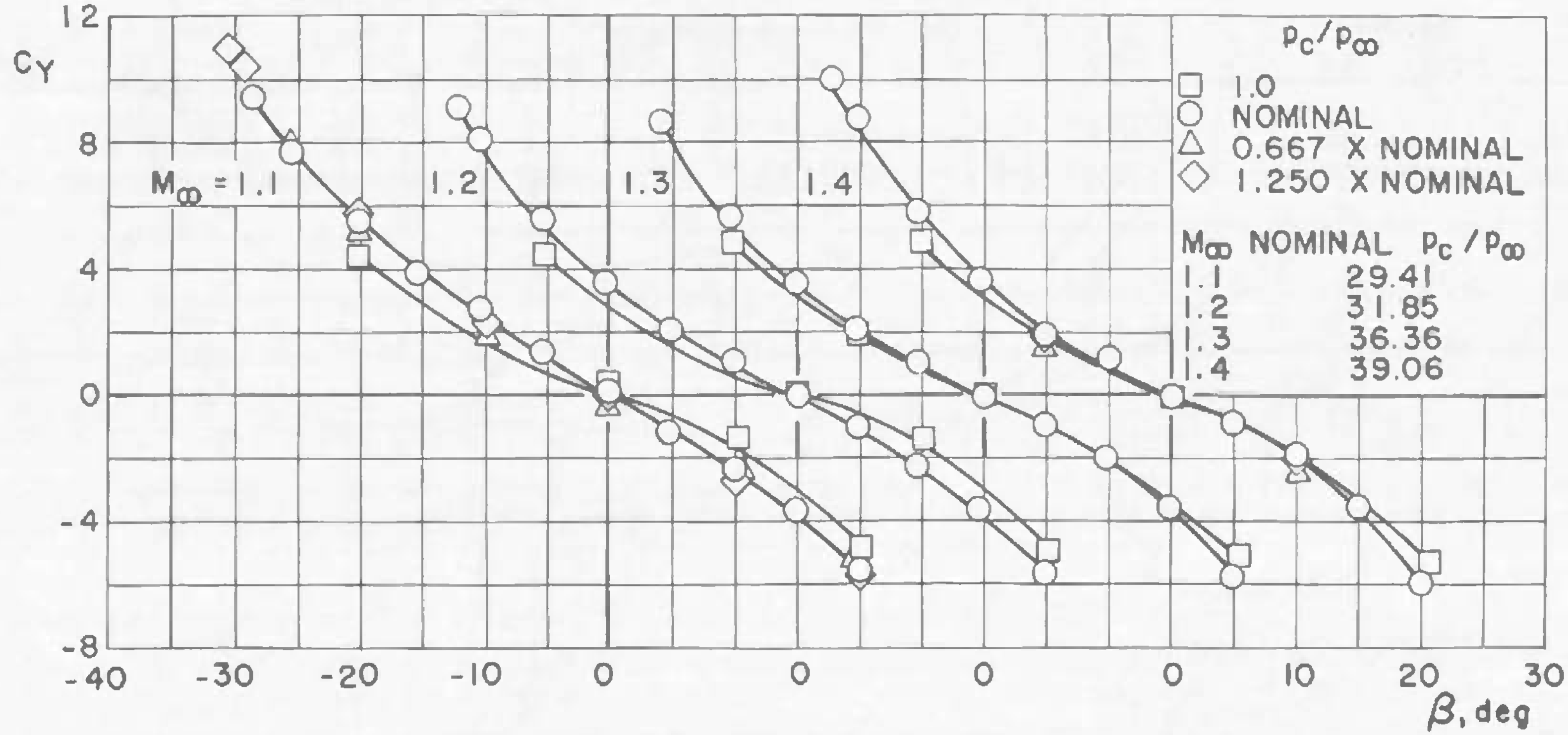
c. Mach Numbers 1.8 to 3.0

Fig. 9 Concluded



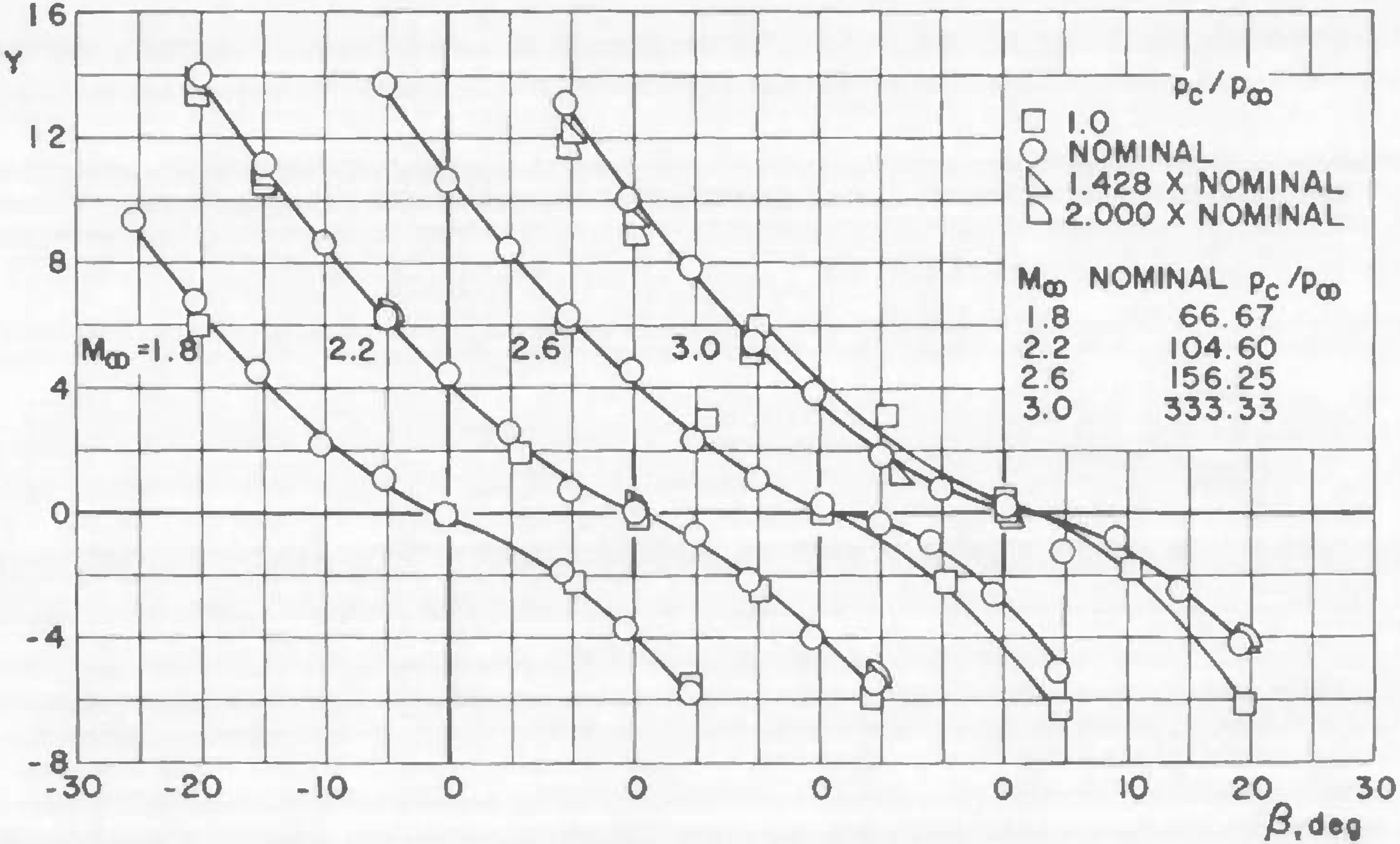
a. Mach Numbers 0.6 to 1.0

Fig. 10 Effect of Jet Pressure Ratio on Side-Force Coefficient for Various Mach Numbers throughout the Angle-of-Sideslip Range, $\alpha = 0$ deg



b. Mach Numbers 1.1 to 1.4

Fig. 10 Continued



c. Mach Numbers 1.8 to 3.0

Fig. 10 Concluded

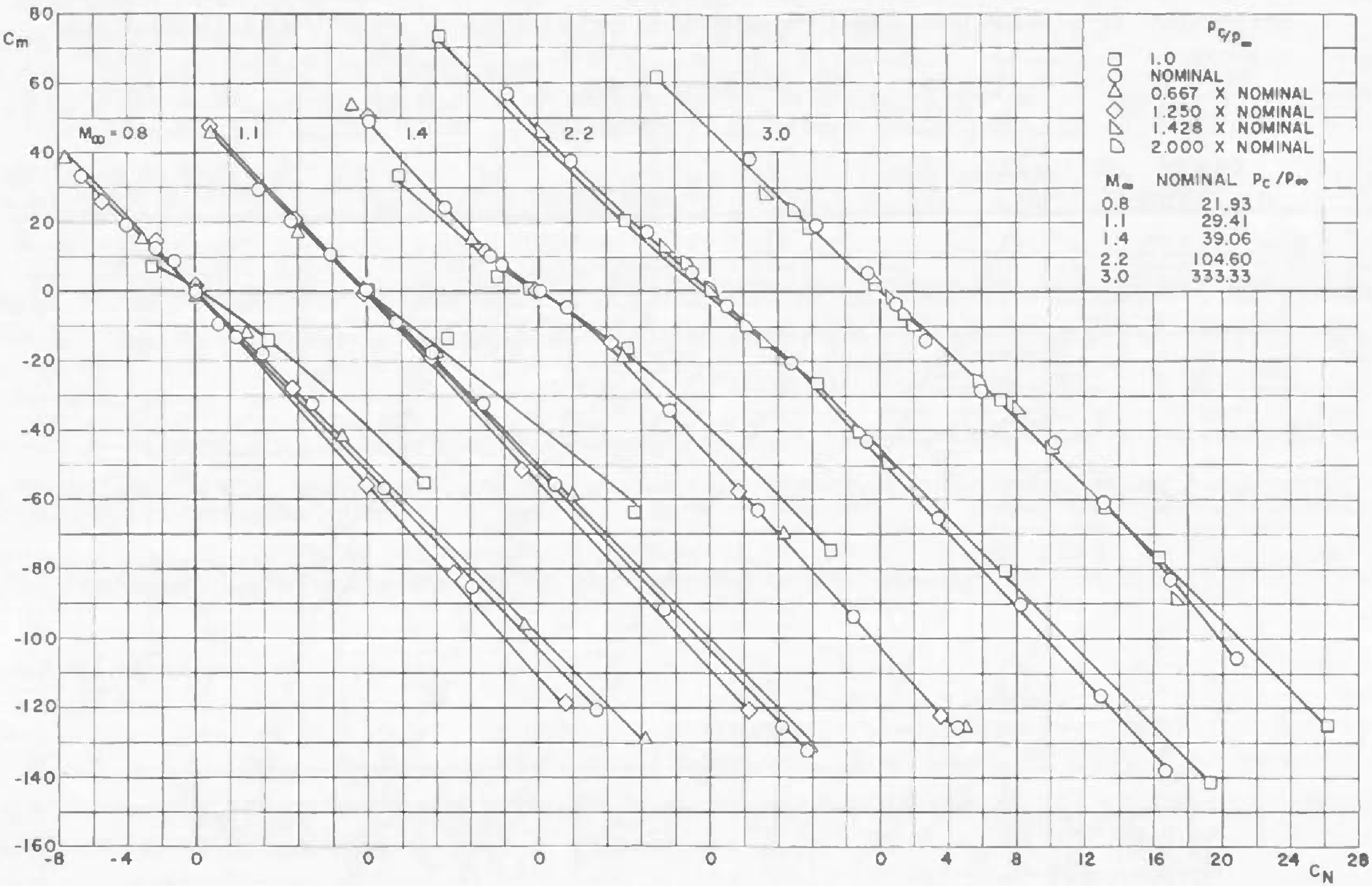


Fig. 11 Longitudinal Stability Characteristics of the Titan III/MOL for Various Mach Numbers, β = 0 deg

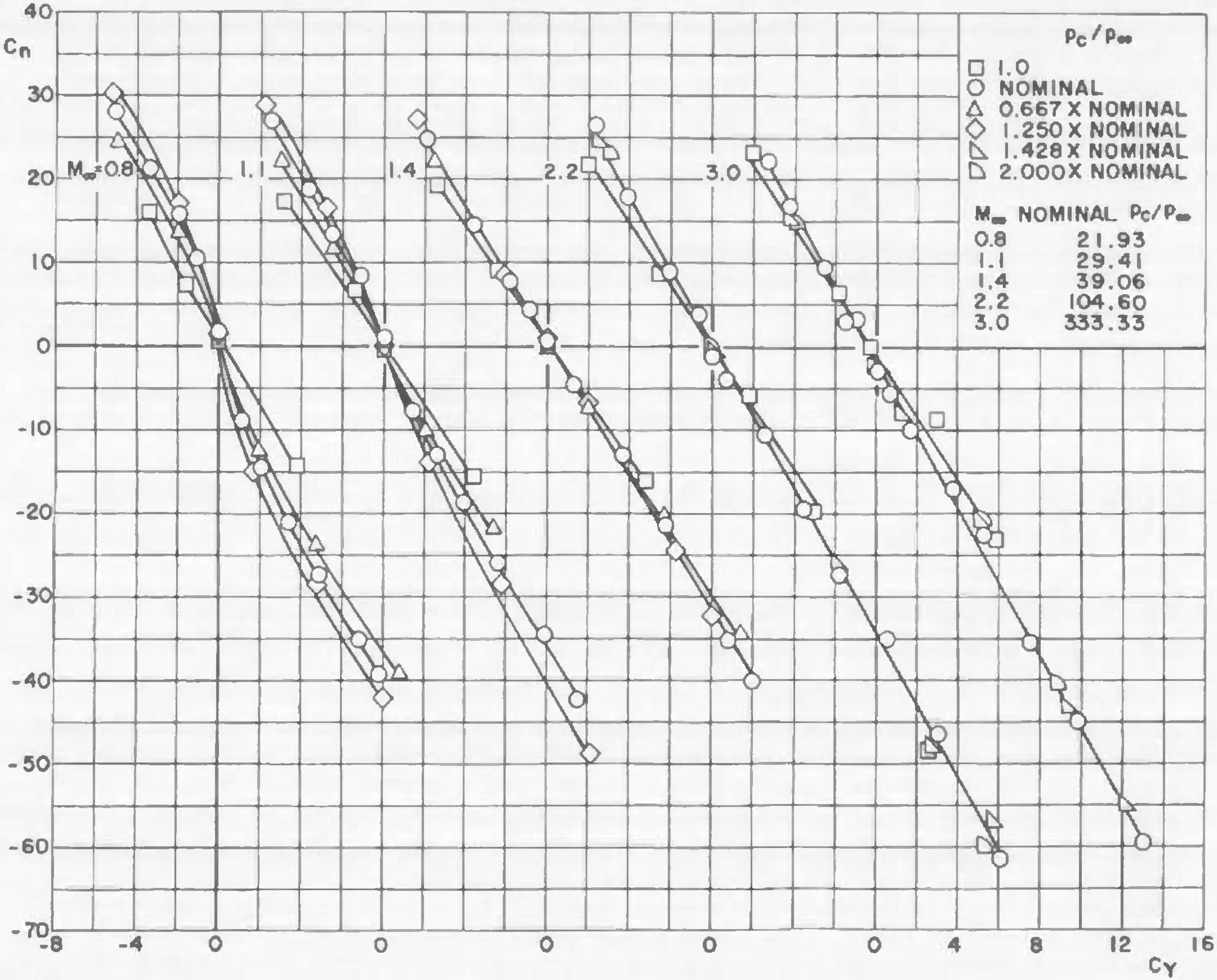
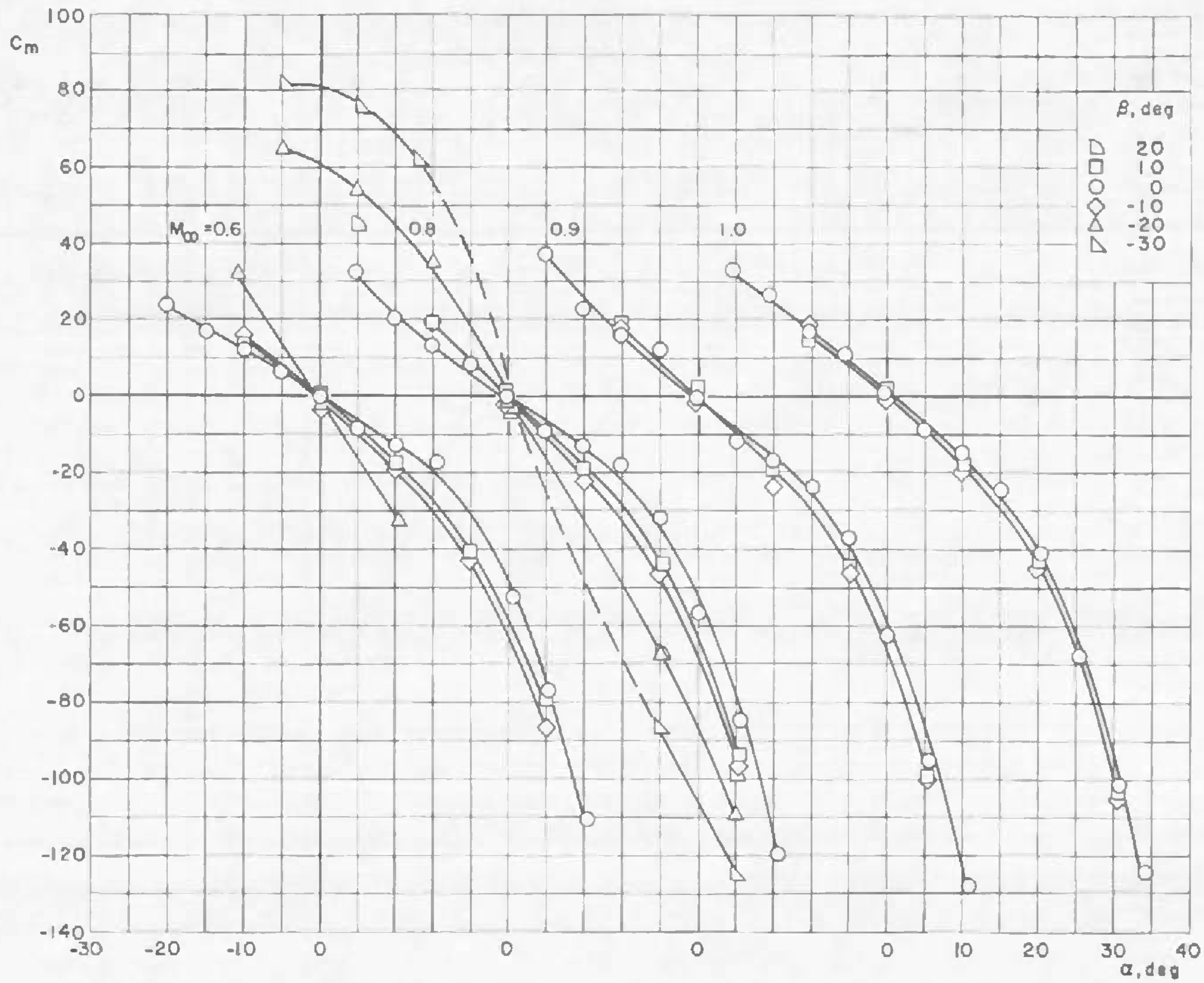
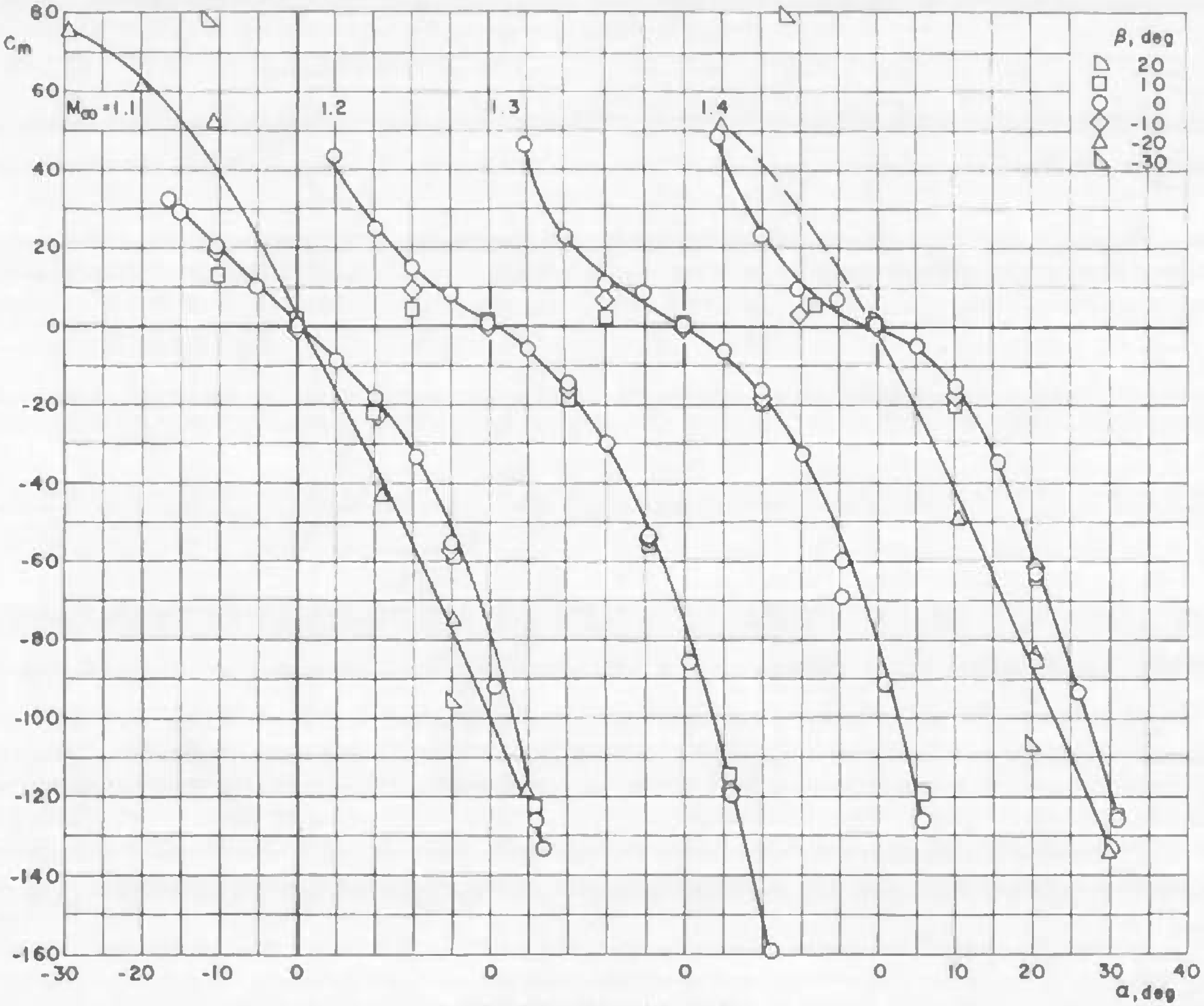


Fig. 12 Effect of Jet Pressure Ratio on Directional Stability Characteristics of the Titan III/MOL for Various Mach Numbers, $\alpha = 0$ deg



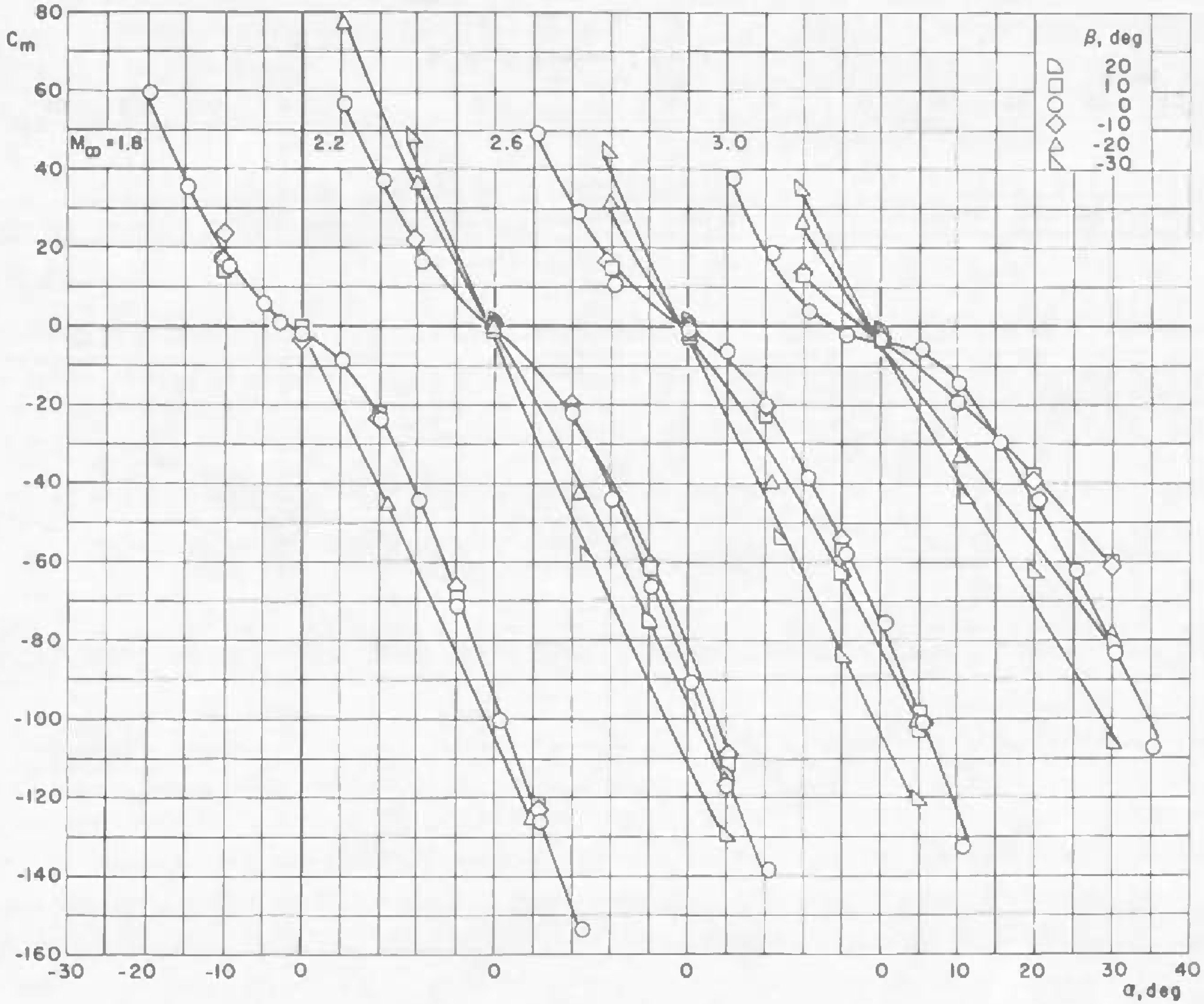
a. Mach Number 0.6 to 1.0

Fig. 13 Effect of Angle of Sideslip on Pitching-Moment Coefficient for Various Mach Numbers throughout the Angle-of-Attack Range at Nominal Jet Pressure Ratio



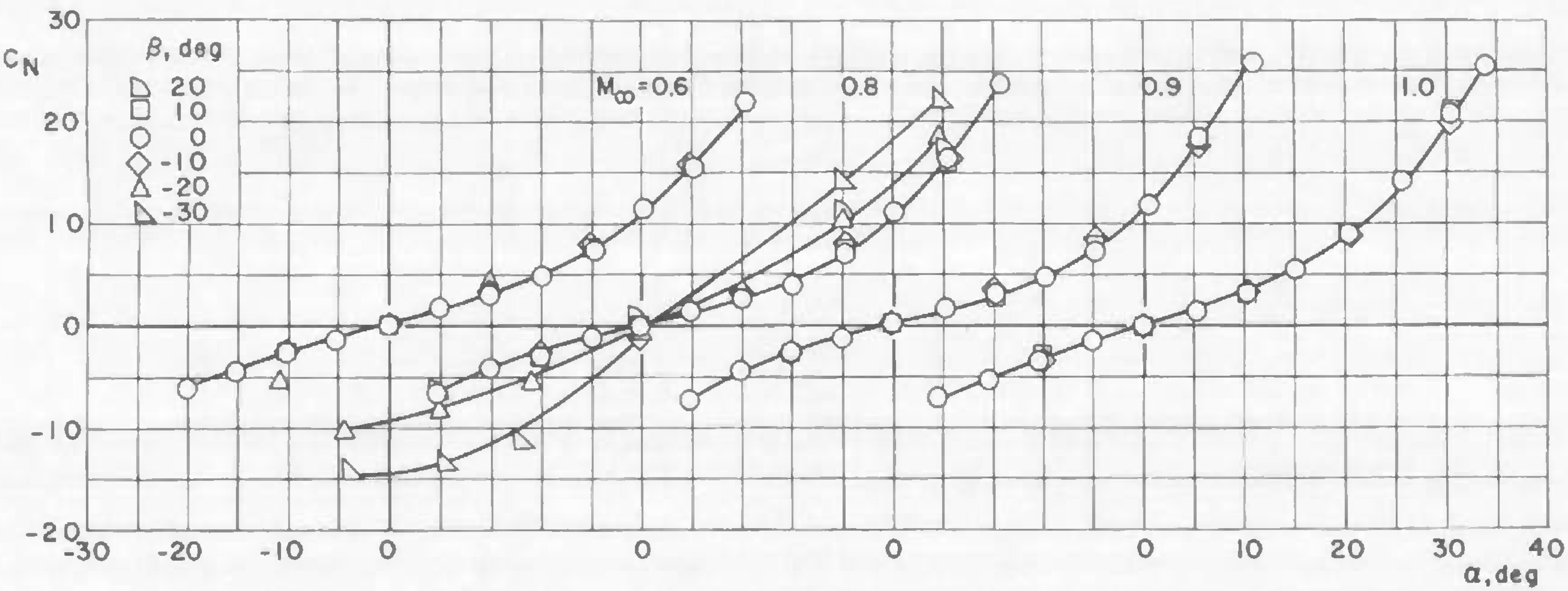
b. Mach Numbers 1.1 to 1.4

Fig. 13 Continued



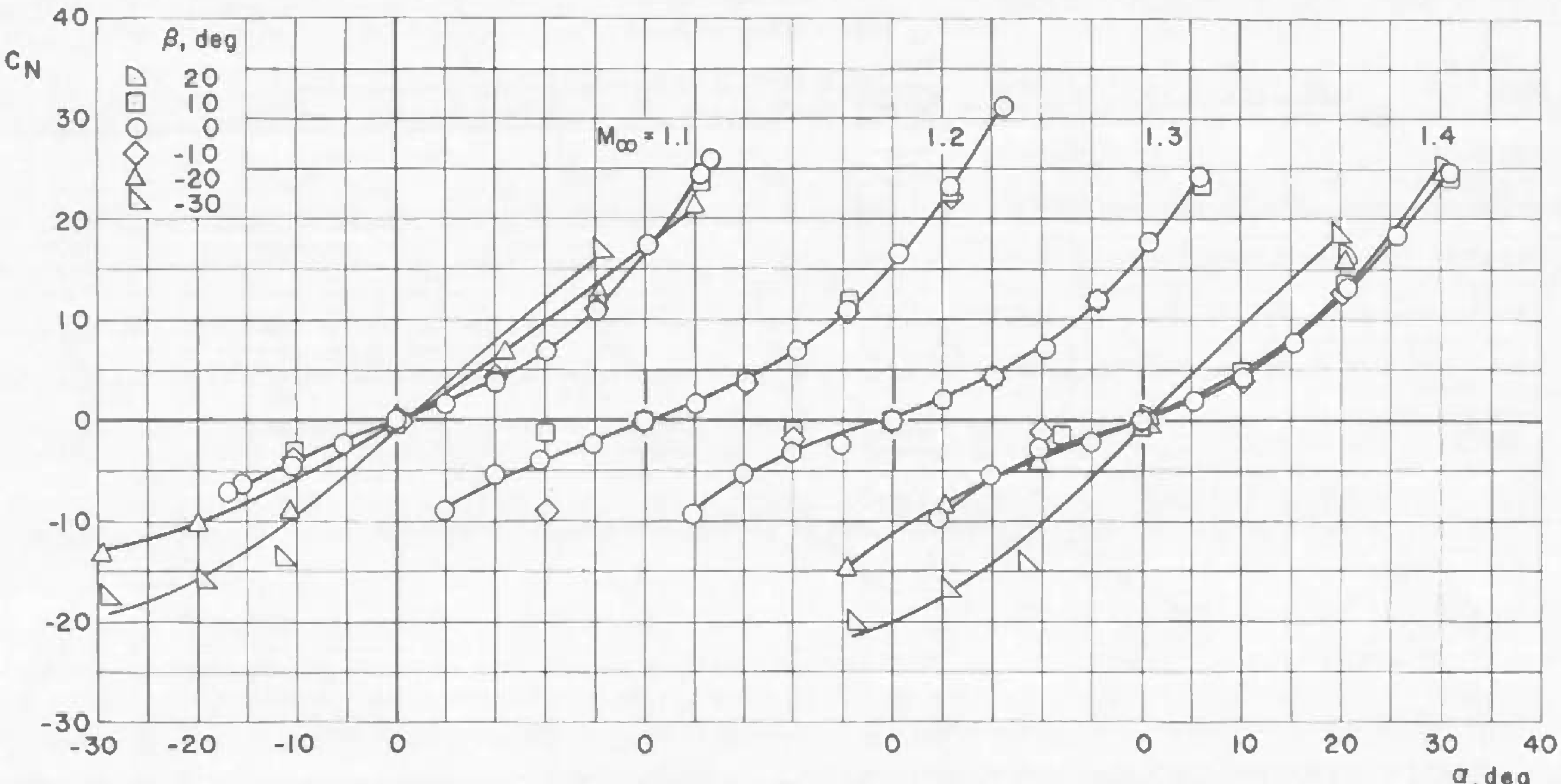
c. Mach Numbers 1.8 to 3.0

Fig. 13 Concluded



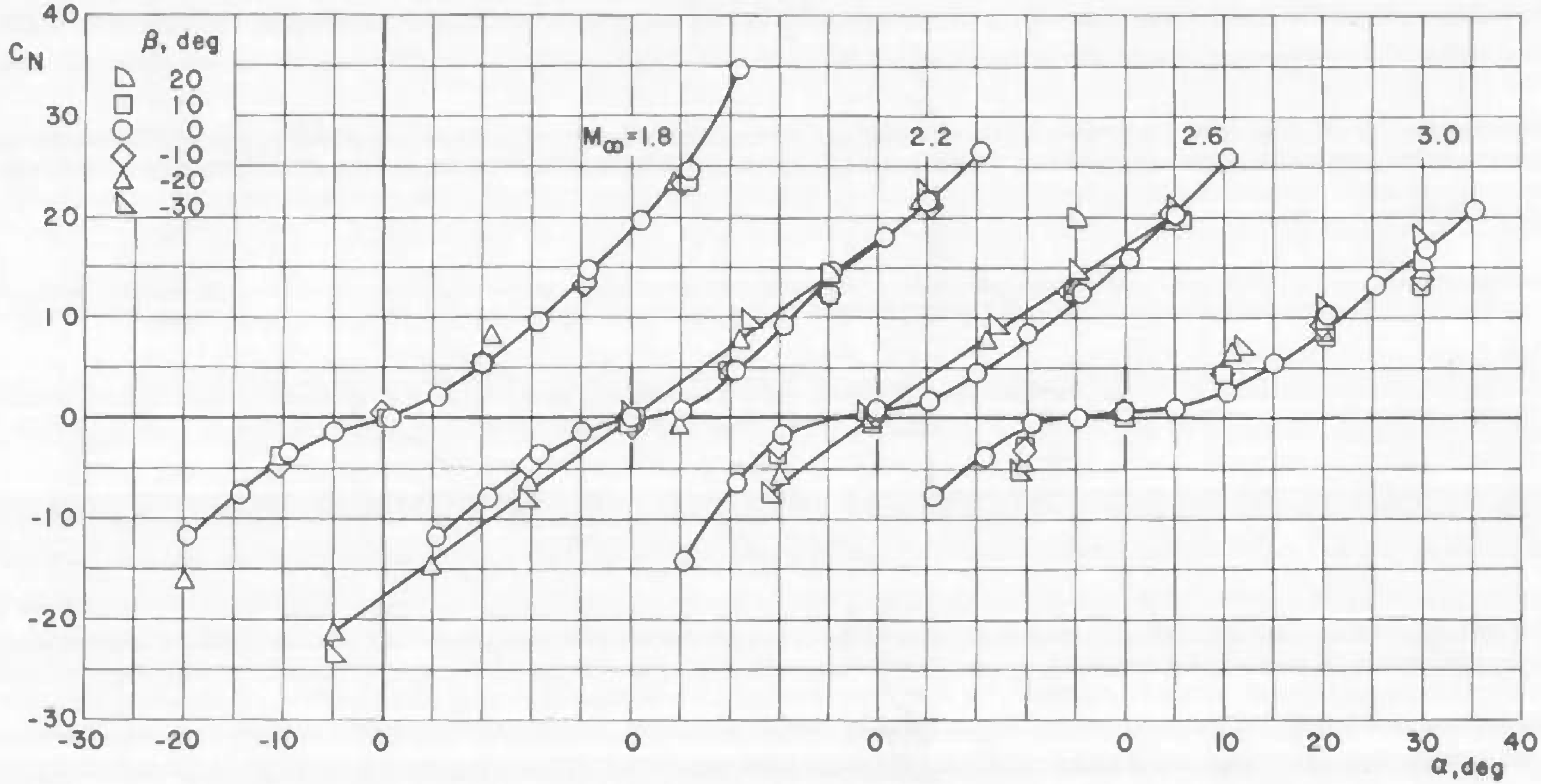
a. Mach Numbers 0.6 to 1.0

Fig. 14 Effect of Angle of Sideslip on Normal-Force Coefficient for Various Mach Numbers throughout the Angle-of-Attack Range at Nominal Jet Pressure Ratios



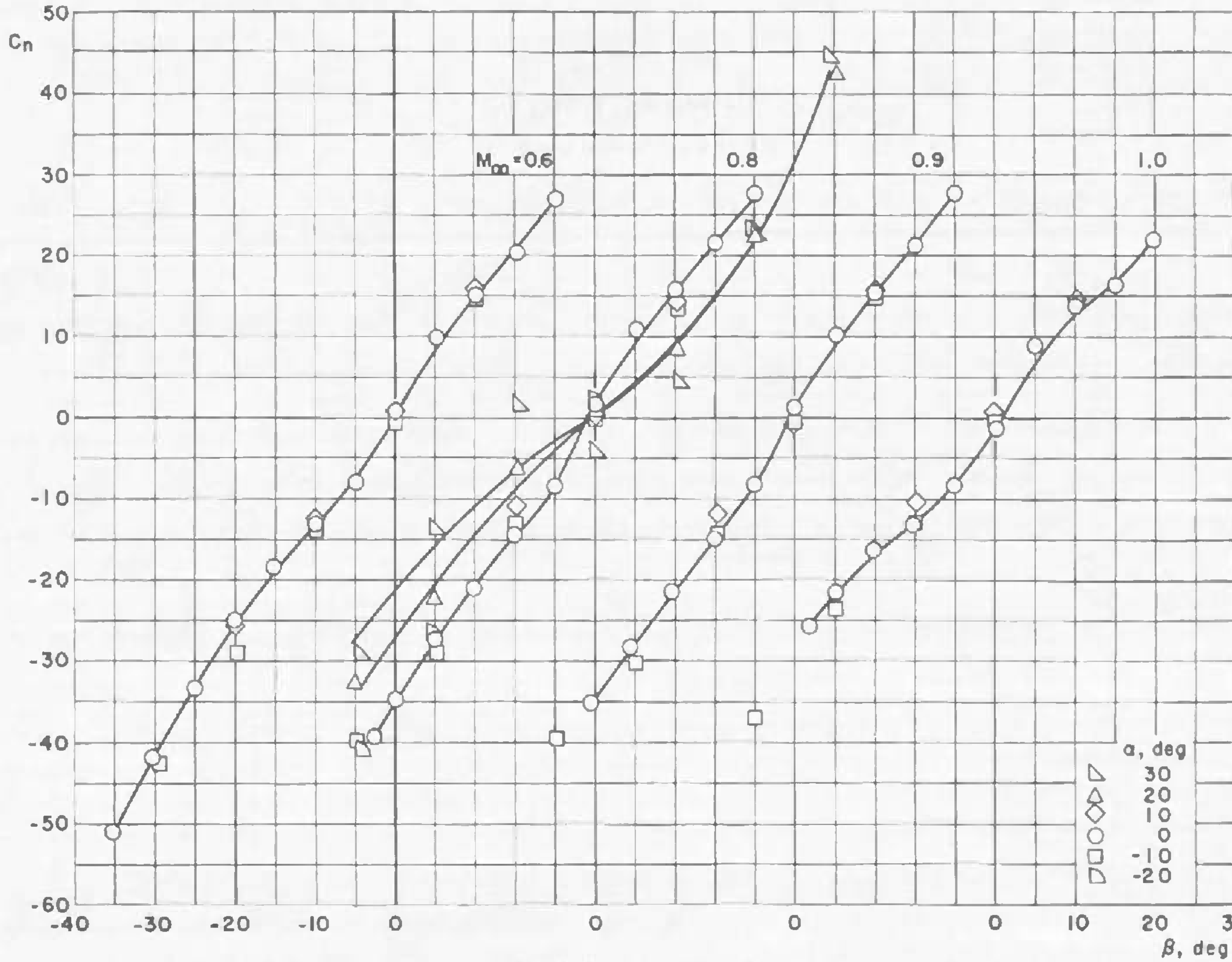
b. Mach Numbers 1.1 to 1.4

Fig. 14 Continued



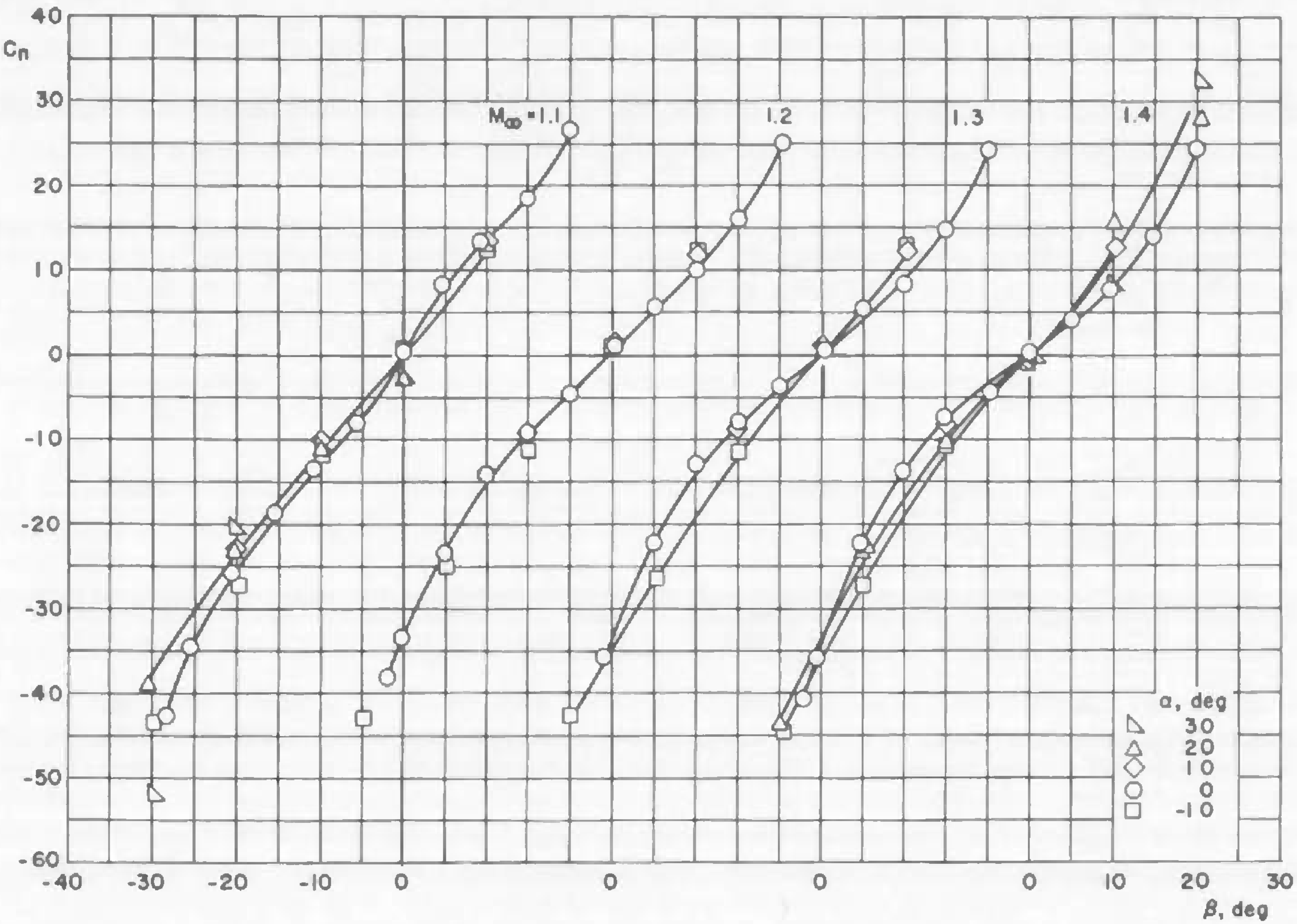
c. Mach Numbers 1.8 to 3.0

Fig. 14 Concluded



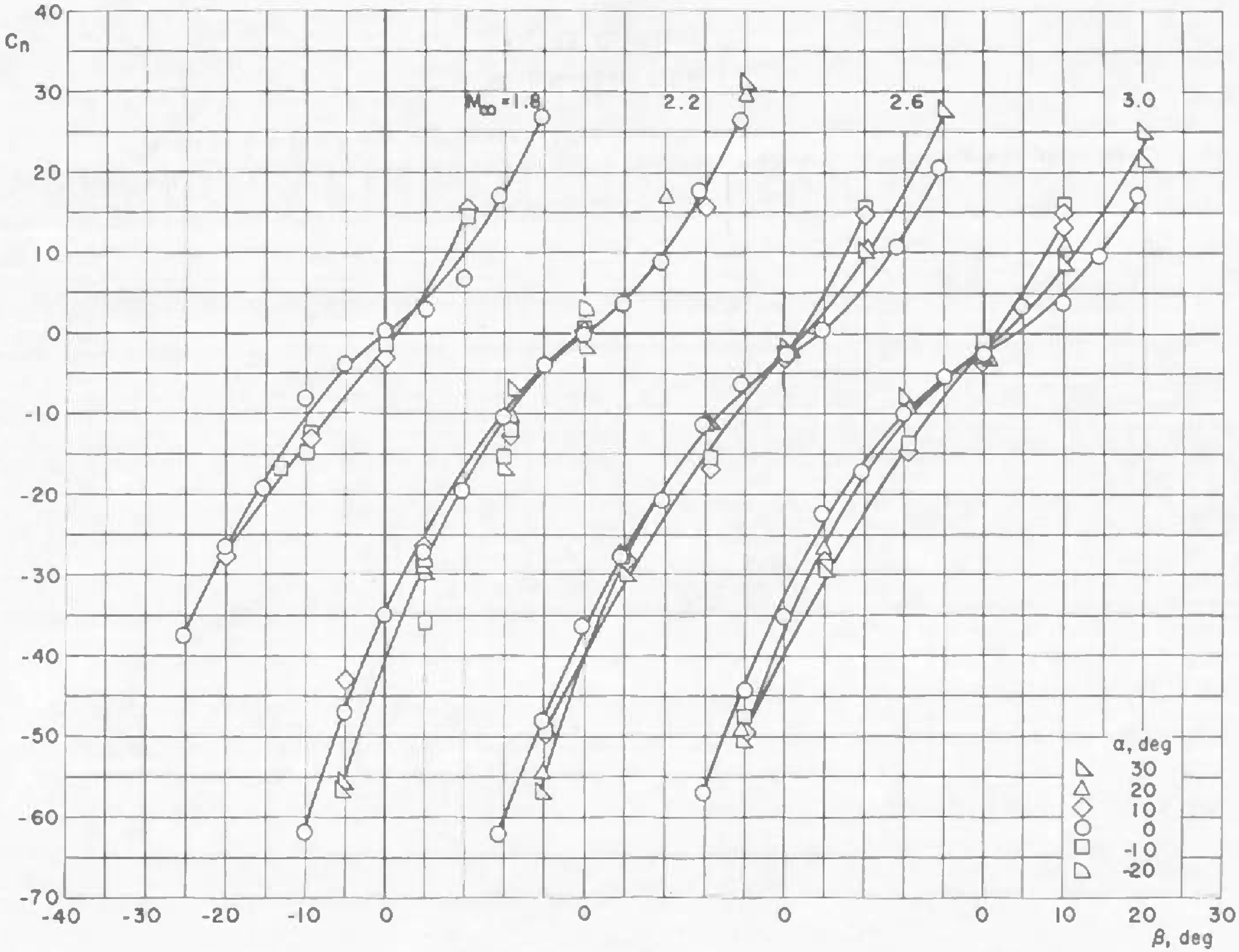
a. Mach Numbers 0.6 to 1.0

Fig. 15 Effect of Angle of Attack on Yawing-Moment Coefficient for Various Mach Numbers throughout the Angle-of-Sideslip Range at Nominal Jet Pressure Ratios



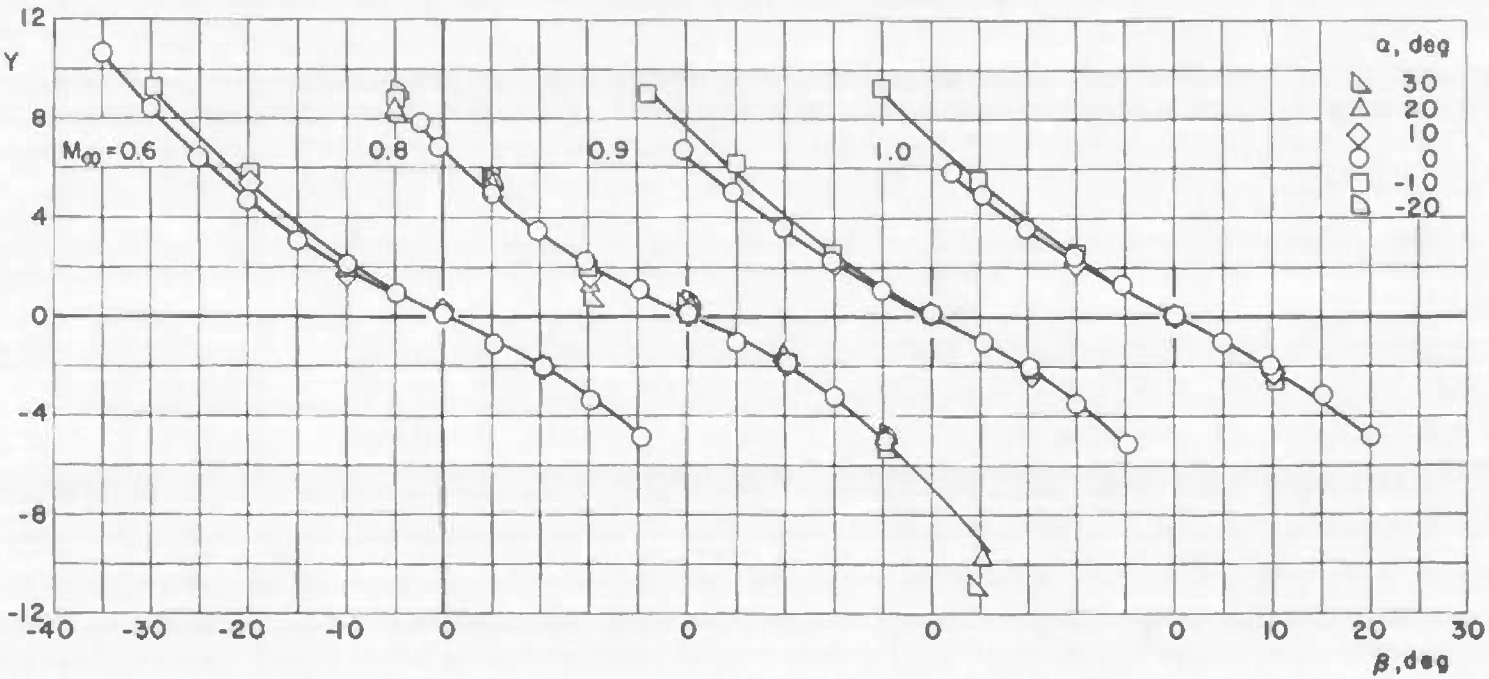
b. Mach Numbers 1.1 to 1.4

Fig. 15 Continued



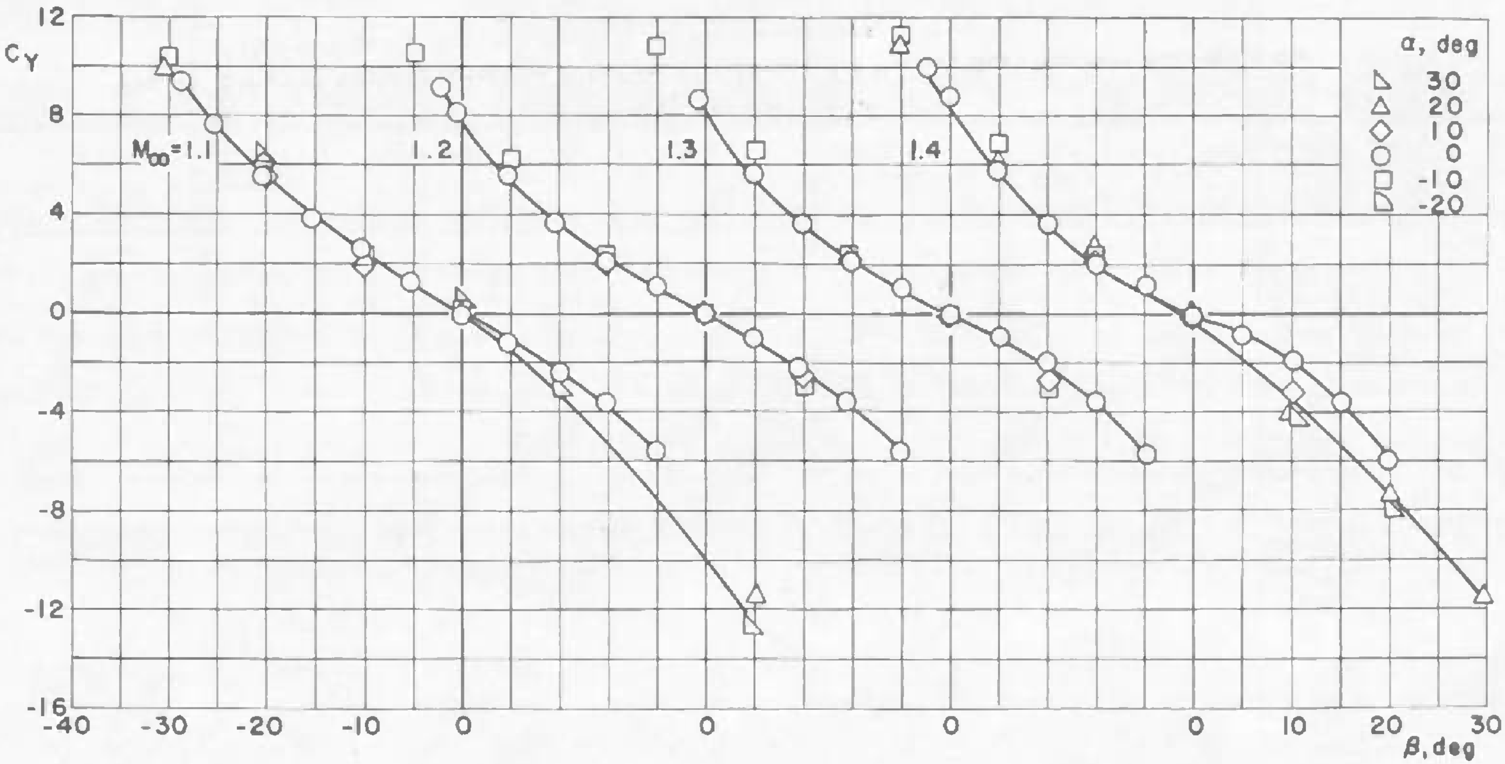
c. Mach Numbers 1.8 to 3.0

Fig. 15 Concluded



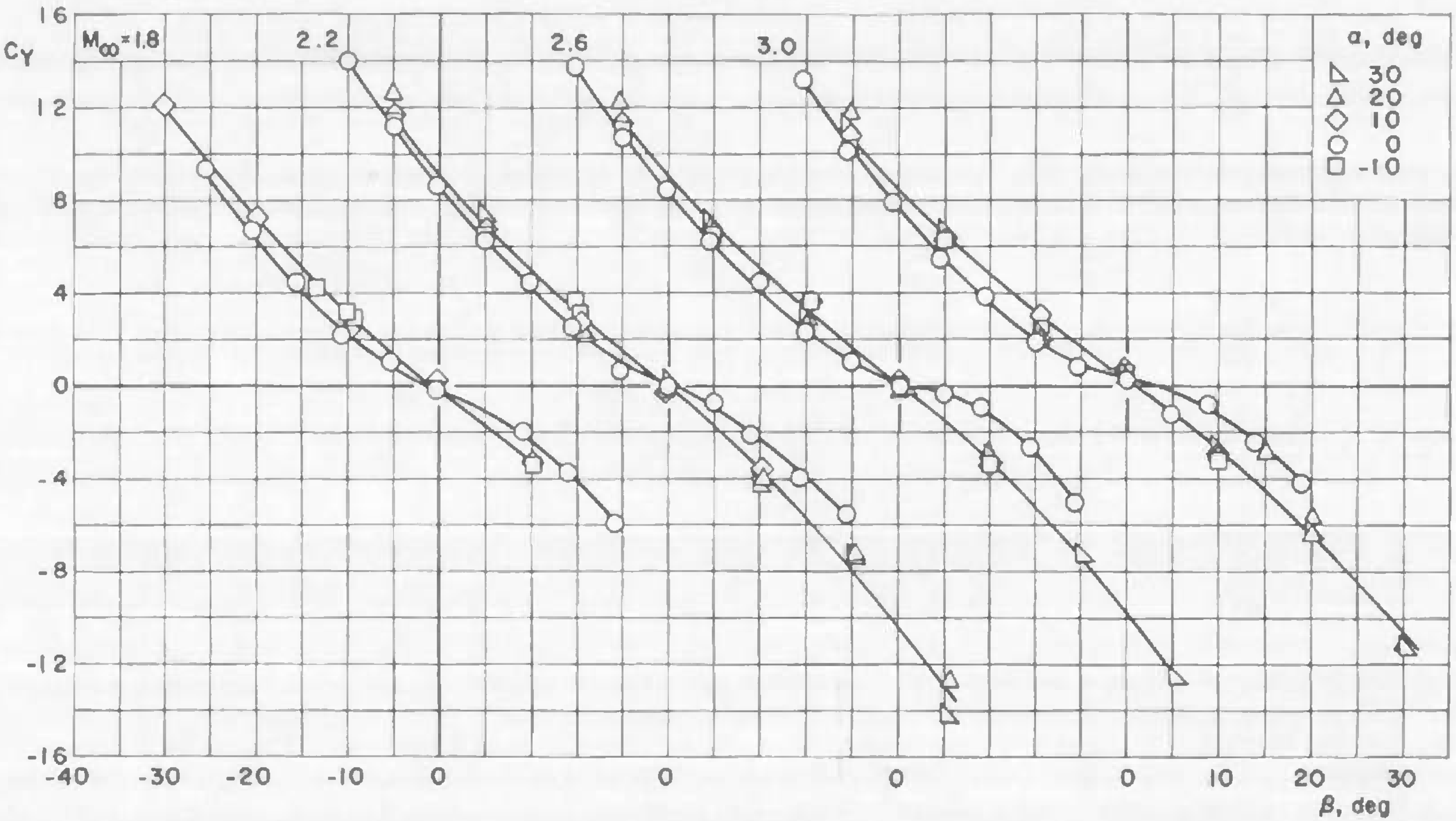
a. Mach Numbers 0.6 to 1.0

Fig. 16 Effect of Angle of Attack on Side-Force Coefficient for Various Mach Numbers throughout the Angle-of-Sideslip Range at Nominal Jet Pressure Ratios



b. Mach Numbers 1.1 to 1.4

Fig. 16 Continued



c. Mach Numbers 1.8 to 3.0

Fig. 16 Concluded

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13 ABSTRACT

A 0.03-scale model of the Titan III/Manned Orbiting Laboratory (MOL) launch vehicle was tested in Tunnels 16T and 16S of the Propulsion Wind Tunnel Facility at Mach numbers from 0.6 to 3.0 to obtain aerodynamic force and moment data on the airborne vehicle during the abort sequence. Test results show that there was a reduction in magnitude of the pitching-moment and normal-force coefficients at all angles of attack as jet pressure ratio (p_c/p_∞) was increased. Thrust termination (jet off to jet on) resulted in an increase in the magnitude of both the yawing-moment and side-force coefficients at all angles of attack.

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transonic flow						
supersonic flow						
thrust termination						
solid-propellant rocket motors						
jet pressure ratio						
stability characteristics						

1. Missiles -- Titan ~~III~~

3. Space vehicles -- ~~about~~ Aerodynamic

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